[redacted]

ELEMENTS

OF

METEOROLOGY;

BEING THE THIRD EDITION, REVISED
AND ENLARGED, OF

METEOROLOGICAL ESSAYS,

BY THE LATE

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TWO VOLUMES.

VOLUME THE FIRST.

LONDON:
JOHN W. PARKER, WEST STRAND.

M.DCCC.XLV.

LONDON:
HARRISON AND CO., PRINTERS,
ST. MARTIN'S LANE.

ADVERTISEMENT.

THE sudden decease of the lamented Author of the present Work, whilst it was passing through the press, has rendered it necessary that the reader should be briefly informed of the nature and extent of the task that has devolved upon the Editors.

During the printing of the first volume, Mr. C. Tomlinson and myself had revised the sheets as they passed through the press, and we had frequent conversations with the Author on various points of the Work, so that we were well acquainted with his general views. On his death the MS. was placed in my hands with a request that I would superintend the continuance of its publication; Mr. Tomlinson kindly expressed his willingness to assist me in the task, which we have therefore jointly executed.

With the exception of the description of the Maps, which terminates the first volume, the whole of this part of the Work was in type at the time of Professor Daniell's death, and had received his final corrections. The Meteorological Charts were also very nearly com-

plete. For the second volume, also, nearly all the materials were prepared. To the Essay on the Water-Barometer has been added a short account of the re-filling of the instrument, at which I assisted, and which I drew up from notes taken at the time. The only part left incomplete was the Essay on the Climate of London, and for this the Author had prepared the Tables and other materials; we have, therefore, only altered the figures in the averages where necessary, and these alterations have scarcely affected the general train of reasoning adopted in the Essay. In a note, at p. 318 of the second volume, we have stated our reasons for giving the additional Table of the Dew-point, and other calculations depending upon it, and for adopting in the text the conclusions thus obtained. We have likewise, for obvious reasons, omitted the comparison of the Meteorological Observations of the three years on which the Author founded the original Essay, with the natural history of the same period. No corresponding materials for a similar comparison of the seventeen years which form the basis of the present Essay had been collected. It would have been easy for us to have extended the Essay, as the Author himself would probably have done, by comparing each year with the mean, and the extreme years together, a comparison highly interest-

ing and valuable; but we felt that in so doing we should be transgressing our duty as Editors. Possibly, had the life of the Author been spared, he might likewise have made further additions to the Essay on Atmospheric Electricity, as the subject had for some months before his death occupied a considerable share of his attention.

From what has been stated above, it will be seen that our duty as Editors has been little more than that of revising the proof-sheets as they passed through the press, and that the Work itself was left in almost a finished state by the excellent man and distinguished philosopher, whose premature loss must long be deplored by the scientific world.

We have prefixed to this Work a short Memoir of Professor Daniell's Life, from the pen of one of his intimate friends.

WILLIAM ALLEN MILLER.

King's College, London,
July, 1845.

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MEMOIR.

John Frederic Daniell, late Professor of Chemistry in King's College, London, was born in Essex-street, Strand, March 12, 1790. He was the eldest son of George Daniell, Esq., of Westhumble, Surrey, a Bencher of the Middle Temple, by whom he was provided with an excellent classical education under his own roof.

Like many others who have become distinguished in science, Mr. Daniell evinced in his boyhood a remarkable love for natural and experimental philosophy. At an early age he was placed in the sugar-refining establishment of a relative, where he introduced some important improvements in the manufacture.

The same love for the pursuits of physical science led him to attend the lectures of Professor Brande, and thus commenced an acquaintance with this distinguished chemist, which soon ripened into a friendship, that terminated only with his death. In company with this gentleman he made several tours, both in the British islands and on the Continent. In 1816, they started the *Journal of the Royal Institution*, afterwards called the *Quarterly Journal of Science and Art*. The first twenty volumes of this periodical were conducted under their joint superintendence. In this Journal were published Mr. Daniell's earlier researches, consisting of numerous papers on subjects connected principally with Chemistry and Meteorology. Among these, a description of his Dew-Point Hygrometer appeared in 1820. This perfect and elegant instrument first gave to hygrometry a definite form,

for by it an observer may, by the mere inspection of a table, ascertain the tension of aqueous vapour at any given spot, and the actual amount of vapour present in a given bulk of air. A full description of this instrument and its various applications, is given in the second volume of the present work. The longer it is employed, the more entirely are its merits appreciated, and the accuracy of its results confirmed. It remains unequalled, and is still the standard to which all other hygrometers are referred.

These Essays were collected in 1823, and incorporated into the first edition of the present work. It would be superfluous to enter into a detailed analysis of this treatise. It will be sufficient to say that it was the first attempt to seize Meteorological phenomena in their most general point of view, and to reduce them *as a whole*, to the known laws of physics. This, for isolated portions, had already been done; but Mr. Daniell was the first to deduce from well-established premises, the laws of the earth's atmosphere. By the process of deduction, he was enabled to discover the existence of two equal, continuous and opposite currents, between the equator and the poles, both in the northern and the southern hemisphere, the lower current constantly setting in from the poles, the upper as constantly returning from the equatorial to the polar regions. He further showed the dependence of the height of the barometric column upon the balance of these two immense currents, which result from the expansion of the air in the torrid or central portions of the earth, the consequent ascent of the heated particles and their replacement by fresh cooler portions from the poles. He was thus enabled to explain the phenomena of the trade winds, and to assign a probable reason for the horary oscillations of the barometer, as well as to anticipate the occurrence towards the poles of a

minimum corresponding, in point of time, with the maximum at the equator; an anticipation, the correctness of which, has been completely verified by observations undertaken at his request for this special purpose by Capt. Sir Edward Parry in his third Arctic voyage.

Mr. Daniell also called particular attention to the great care necessary in the construction of meteorological apparatus, and gave directions by which barometers might be made with facility and certainty. He further suggested a regular plan for observing meteorological instruments; and in the second edition of this work, in 1827, he particularly pointed out the importance of determining the amount of solar radiation, and of the cooling of the earth by uncompensated radiation into space. The value of these suggestions is amply attested by their general adoption in the modes of observation now employed in the National Observatories, where they have been extended considerably beyond what was originally proposed by the author.

In 1824, he contributed an important paper to the *Transactions of the Horticultural Society*, entitled, "On Climate; considered in its applications to Horticulture." The Society immediately testified their sense of its value by awarding to him their silver medal, and practical men were not slow in availing themselves of the valuable suggestions with which it abounds*.

In September, 1817, he married Charlotte, youngest daughter of the late Sir William Rule, Surveyor of the Navy, and fixed his residence in Gower-street. His mind was ill-adapted for the details of mercantile pursuits, and he

* See a note at the conclusion of this Essay, which is inserted in the second volume of this work, (p. 247.)

was therefore but too glad to escape from their trammels; and in after life he used often to refer to his retirement from business as a matter of congratulation. He now became Managing Director of the Continental Gas Company, to forward the interests of which he visited the principal cities of France and Germany, in company with Sir William Congreve and Colonel Landmann, making those arrangements by which many of the continental towns have since been lighted. His attention was thus necessarily directed to the processes of manufacturing gas for the purposes of illumination. A patent had been taken out for procuring gas from oil by destructive distillation. The oil was caused to fall drop by drop into retorts filled with fragments of bricks heated to redness; it was decomposed, and the gas thus furnished was condensed by pressure into strong iron vessels, and constituted the well-known portable gas. It was soon found, however, that oil was too expensive a combustible to be used with advantage in this manufacture; and Mr. Daniell, in consequence, instituted a series of experiments, which ended in his invention of a process in which common rosin was substituted for the oil. The rosin was dissolved in oil of turpentine; this fluid was, as before, allowed to trickle into the heated retorts; but the turpentine being very volatile distilled immediately and was condensed in appropriate vessels, while the rosin alone underwent decomposition. The process answered perfectly: negociations were entered into with some of the American States, the plan was adopted, and some of their cities still continue to illuminate their streets with gas thus obtained. In England, however, it was soon laid aside, as unforeseen objections prevented the employment of the *portable* gas, to which alone it was applicable; for although in illuminating power it far surpasses our coal gas, yet the

low rate at which coal may be obtained in this country, more than counterbalances the disadvantage resulting from the inferior quality of the gas obtained from it, and renders inexpedient the application of rosin gas to the general purposes of illumination.

In 1827 Mr. Daniell engaged warmly in the formation of the Society for Promoting Useful Knowledge, and wrote and edited several of the books published under their auspices; among others, the treatise on Chemistry. Latterly, however, he ceased to take an active part in this Society; and soon after the commencement of the *Penny Cyclopædia*, withdrew his name.

His reputation had been established as a diligent and successful cultivator of this science by the publication, in the *Quarterly Journal*, of many valuable papers on subjects connected with Chemistry, particularly several on Crystallization. On the foundation of King's College, in 1830, he was appointed Professor of Chemistry, a post which he occupied till the time of his decease.

At this time he invented a new Register Pyrometer, for ascertaining high temperatures, such as the heats of furnaces, and the melting points of metals, an account of which was inserted in the *Philosophical Transactions* for 1830; and in the following year (1831,) he published a second Essay upon the same subject, showing the application of this instrument, on a more extended scale, to the measurement of the expansion of solid bodies. To these papers the Royal Society, in 1832, awarded the Rumford Medal, a triennial prize for the most important discovery in the philosophy of heat, or its practical applications, that may have been published throughout the world since the time of its last award.

In the same year, he gave an account of a Water-Baro-

meter which he had recommended the Royal Society to erect, in order that more accurate observations might be instituted on the fluctuations of the atmospheric pressure. At the request of the Society, he undertook to superintend the construction of this instrument; the details connected with this operation, as well as an abstract of the observations which were made with it, are reprinted in the second volume of this work.

The year 1834 brought to him his severest trial, in the death of his wife, to whom he was most affectionately attached. For the benefit of her health he had, during the preceding year, removed his family to Norwood, in Surrey, in the hope that the purer air of that spot might restore her enfeebled frame. Here he continued to reside with his family to the termination of his own life.

In the succeeding year commenced those researches in Electricity, which so greatly contributed to establish Mr. Daniell's reputation. The following brief explanation will give the reader an insight into the nature and value of his discoveries in this department of science. The first point to which his inquiries were directed, was the source of power in the voltaic pile, which involved an examination of the cause of the rapid declension of power in batteries of the ordinary construction. This decline he showed to depend principally upon the reduction of the zinc which was dissolved during the action of the battery, and its deposition on the copper plates, so that in time two zinc faces became opposed to each other, and thus the action was suspended. On stripping off the zinc thus deposited, the activity of the arrangement was renewed. The accumulation of hydrogen on the copper plate, he also observed materially to diminish the power of the combination; and he showed that

the main use of nitric acid in the ordinary charge consisted in its power of removing this adherent hydrogen. From these observations he was led to propose a new method of constructing voltaic batteries, and in 1836 he published a paper in the *Philosophical Transactions*, in which he described a form of apparatus, which, from its enabling us to maintain equable continuous and powerful currents of electricity for any required period, he termed the *Constant Battery*. The principle of its construction is exceedingly simple. Zinc and copper are, as in the old arrangement, the metals employed; a rod of amalgamated zinc is placed in dilute sulphuric acid, and this acid is separated from the opposite plate or cylinder of copper, by means of a porous vessel, such as a piece of ox gullet, or a tube of unbaked porcelain; outside this, and in contact with the copper, a saturated solution of sulphate of copper is placed; the porous tube permits the transmission of the electric current, but effectually hinders the intermixture of the two fluids, and thus prevents the precipitation of the zinc upon the copper. In this arrangement no hydrogen can accumulate upon the surface of the copper, which is kept clean and bright by a continual deposition of fresh metallic copper, as in the ordinary process of electro-typing. For greater convenience, this battery is usually arranged in cylinders, the copper forming the case or cell in which the whole is contained, the zinc rod being placed in the axis of the cylinder. Any number of these cells may be connected together in succession, in the manner adopted with the plates of an ordinary Wollaston's battery. By this arrangement a much cheaper and far more powerful combination is produced than any which had been previously obtained, and the annoying extrication of gas, which had been before unavoidable, was completely obviated. Some of the effects produced by a large battery of

seventy cells on this improved construction are detailed in the *Philosophical Transactions* for 1839.

An immense impulse was thus given to the prosecution of research in voltaic electricity, and the fruits of the activity thus induced are abundantly visible in the change which the application of this new power has effected in many branches of art. The whole process of gilding and plating has been changed, new arts introduced, as those of zincing and nickelizing; these, with the processes of electrotyping and glyphography and the uses made of electricity in the blasting of rocks and in submarine operations, may be all traced more or less directly to the facility which the invention of the constant battery has offered to the application of the wonderful agent by which they are effected.

The importance of this invention was immediately recognized throughout the scientific world, and at once gave Mr. Daniell an European celebrity. In 1837, the Royal Society conferred upon him their highest mark of distinction, by awarding to him the Copley Medal. He continued his experiments on various forms of voltaic combinations, and gave the results of his labours to the world in five papers, published in the *Philosophical Transactions*, in the form of letters addressed to Dr. Faraday. The last of these, published in 1842, contains an experimental application of Ohm's mathematical deductions to the complicated cases of voltaic batteries, in which he shows the close accordance of the views of the German mathematician, with facts not only in the simple cases to which he applied it, but also in others, calculated to try it to the utmost, in circumstances of very great complexity.

Having now a powerful and manageable instrument of analysis in his hands, he applied it to the purposes of chemical research, and by two papers published in the *Philosophical*

Transactions for 1839 and 1840, "On the Electrolysis of Secondary Compounds," he showed that in the connection between electricity and chemistry still lay the key to many of the disputed points of chemical theory. Starting with Faraday's law of the definiteness and equality of action at all points of the same circuit, he successfully investigated the general law which regulates the decomposition of neutro-saline liquids. He found that for every chemical equivalent of zinc dissolved in one of the cells of the battery, a corresponding equivalent of the salt is decomposed between the electrodes or poles of the circuit, and that at the same time in the majority of instances an additional equivalent of oxygen and hydrogen is given out in the voltameter. This latter occurrence he showed to be a secondary action, independent of the electric current, and occuring only when the elements of the salt are capable of decomposing water, as when sulphate of soda is employed; but if the ingredients of the compound (as occurs with chloride of copper,) be not capable of decomposing water at the ordinary temperature, neither oxygen nor hydrogen exhibits itself at the electrodes. He thus proved, that when a metallic salt is decomposed, it is its metal which travels to the positive electrode, and not the oxide of the metal, as was previously imagined, whilst the oxygen, if the salt contain any, passes with the acid to the negative electrode; and in further proof of the correctness of this view, he arrested the metal *in transitu*, and caused it to be deposited upon a surface of bladder interposed for the purpose between the electrodes. Powerful experimental support was thus afforded to the theory of Davy of the composition of salts, (now maintained on other grounds by many eminent chemists of the present day): upon this view all saline bodies are referred to a common type, the metal being combined either with a simple

body like chlorine, or with a compound substance equivalent to it in composition, like SO_4; there being upon this hypothesis no such thing as a salt composed of a metallic oxide and an acid. For these important researches he received one of the Royal Medals for the year 1842.

Mr. Daniell's last paper was published conjointly with his friend Dr. Miller, in the *Philosophical Transactions* for 1844, in which were continued the investigations on the decomposition of saline bodies which Mr. Daniell had commenced, and they applied the analysis of the battery to the examination of some theoretical points connected with the phosphates and ferrocyanides; they found also that, contrary to the usually received notion, the metal and the acid are not actually transferred in equivalent proportions to the opposite electrodes, the metal always travelling in smaller proportion than the acid, although an equivalent of each is uniformly set free. Copper, for instance, is not transferred at all, whilst potassium, though it passes over, is carried forward in much less than its equivalent proportion; the cause of these singular phenomena still remains open for inquiry. Practically these effects are well known to those employed in electroplating, and constitute some of the greatest difficulties in the successful conduct of the process.

But whilst thus pursuing investigations into some of the most refined points of chemical theory, Mr. Daniell was not unmindful of his duties as Professor and teacher of the science. In 1839 he published, as a guide to the students attending his Lectures, his admirable *Introduction to the Study of Chemical Philosophy*, "the origin of which," as he says in his preface, "was a desire to present to students of Chemistry an elementary view of the discoveries of Dr. Faraday, in electrical science." The unassuming tone of his preface, however,

would convey a very inadequate idea of the merits and extent of this valuable work, which presents, in a succinct, connected and readable form, a general view of the different varieties of molecular forces, often discussed in a manner both striking and original; in illustration of which, we may particularly refer to the chapter on heterogeneous adhesion, including the phenomena of capillary action and endosmosis. In 1843 a second edition of this work appeared, and a considerable part of the book was reprinted in New York by Professor Renwick, for the purpose of distribution by the State among their schools; and, in a letter to Mr. Daniell, dated 18th June, 1840, Professor Renwick, after apologizing for mutilating the work in order that its size might be sufficiently reduced to render it cheap enough for distribution, says, "You are now, in consequence, made known to the pupils of more than 5000 of these schools, and have probably been already in the hands of 25,000 readers."

But his labours for the benefit of the rising generation were not limited to the performance of his duties as Professor of Chemistry. The success which had attended the establishment of the Medical Department at King's College, (in which a class of students for whom there had hitherto been no systematic provision in the Metropolis, for enabling them to combine with their scientific and professional education the inestimable advantage of a sound moral and religious training, and by which an opportunity was offered to parents of placing them under the discipline of the Established Church,) induced Mr. Daniell to hope that similar advantages might be extended to a numerous and increasingly important body of young men, who were studying with the view of becoming engineers and master manufacturers; and supported by his colleagues he represented the importance of the formation of such a Class

to the Council of King's College; the Council immediately appreciated the value of the proposal, and in consequence the Department of Applied Science was added to the scheme of education adopted in the College; this department has since formed an important Class in the College, and in its success Mr. Daniell always took the deepest interest.

The reputation he had acquired by his electrical researches induced the Admiralty, in 1839, to place him upon the commission for inquiring into the best method of defending the Royal Navy from lightning, comprising as its members "Admiral Griffiths, Admiral Sir J. Gordon, K.C.B., Captain Ross, R.N., Professor Daniell, Mr. Fincham, master shipwright of Her Majesty's dockyard, Chatham, and W. Clifton, Esq., Secretary." In the Report published by the Commissioners they recommended the adoption of Mr. Snow Harris's conductors, a recommendation which the Government shortly afterwards ordered to be followed.

A vacancy having occurred in the post of Foreign Secretary to the Royal Society, in consequence of the resignation of Captain Smyth, Professor Daniell was appointed to that office.

In the year 1836, a letter was addressed to the President of the Royal Society by Baron Humboldt, pressing upon this body the importance of establishing a combined system of magnetic observations over a large extent of the earth's surface, in order to determine various important questions relating to the phenomena of terrestrial magnetism. In furtherance of the plans recommended in this letter, representations were made to Government by the Royal Society, and supported by the British Association; in consequence of which the recent Antarctic Expedition was equipped, and Magnetic and Meteorological Observatories were established

in various parts of the British dominions. In order to ensure the fullest advantages from these measures, the Admiralty applied to the Royal Society for instructions as to the nature and extent of the observations it would be desirable to institute, and for the best method of carrying out the objects designed. In compliance with this requisition, a Report upon these subjects was made by the Royal Society's Committee of Physics, including Meteorology, which was afterwards published by the Society. From his intimate acquaintance with Meteorology, both theoretical and practical, the Committee requested Professor Daniell to prepare the Meteorological part of this Report; and he accordingly drew up a paper which formed the basis of that portion of the work. The recommendations contained in the Society's Report have been adopted, not only in our own, but also in the foreign Observatories acting in co-operation with those established by the British Government.

In April, 1840, Mr. Daniell was requested by the Admiralty to examine several specimens of water taken up at different points along the coast of Africa, with the view of ascertaining the cause of the rapid corrosion of the copper sheathing on the ships employed upon that station. Analysis of the water soon convinced him that the destructive agent was sulphuretted hydrogen, which he found in six out of the ten specimens analysed; and upon examining the corroded copper, he found it partially converted into sulphuret. He proposed to remedy the evil in some measure by the employment of zinc protectors, which, by means of moveable bolts, could be brought into action when the vessel was in the infected locality, and again withdrawn when it left the neighbourhood; by this simple precaution, the mischief of *over-protection*, which impaired the value of Davy's ingenious

and valuable suggestion, might be completely obviated. His Report upon this subject was deemed of such importance that the Admiralty, through Sir John Barrow, published it in the *Nautical Magazine* for 1841; he also made it the object of some further investigation, and gave a lecture upon the subject at one of the Friday evening meetings of the Royal Institution: this lecture appeared in the *Philosophical Magazine*, and a translation of it was published in one of the numbers of the *Annales de Chimie* for 1841.

The following year his scientific labours received a well-merited testimony of respect from the University of Oxford, who conferred upon him the honorary degree of D.C.L.

During the winter of 1841 he was seized with a dangerous attack of hæmoptysis, which for several days occasioned the most serious apprehensions as to the result, as the nature and cause of the symptoms were extremely obscure, and the active treatment which was resorted to in the hope of checking the effusion of blood, seemed for a time unavailing. It at length appeared that the hemorrhage had been caused by the separation of a bronchial polypus; as soon as this was completely removed by the process of expectoration, he rapidly amended, and to all appearance regained his usual health. His system, however, seemed never completely to recover its tone; and he was himself, as it appeared from memoranda made by him some time before his death, under an impression that he had *angina pectoris*, or some affection of the heart, from which it was not improbable he might at some time be suddenly cut off. He had, for some months before his death, complained of pains in the chest and arms, of a rheumatic character, which appeared principally referable to impaired digestion, though he himself referred them to the heart;

after his death, however, not the slightest trace of disease in this organ could be discovered.

On the 13th of March, 1845, he delivered his customary lecture at three o'clock in the afternoon, at King's College, apparently in his usual health, and in the course of the day he had seen and conversed with several friends with his wonted cheerfulness; at four o'clock he went over to attend in his place as Foreign Secretary, at a meeting of the Council of the Royal Society at Somerset House. He took part in the proceedings of the meeting, and had just made some remarks relative to the water-barometer, the reboiling of which, at the request of the Society, he had superintended, when, on resuming his seat, his eyes were observed to become fixed, his breathing laborious, and at last stertorous. Several medical men were present, who instantly hastened to his assistance; he was immediately bled, but without deriving from it the slightest relief, and in less than five minutes from the seizure he was a corpse.

The shock which this sad event occasioned was by no means limited to those who were present at the Council meeting, among whom were many of his intimate friends. The news spread rapidly through the town, and brought consternation and sorrow to many circles. By order of the Noble President of the Royal Society, who was present on the melancholy occasion, the ordinary meeting of the Society, which should have been held that evening, was postponed, as a mark of respect to Mr. Daniell's memory.

An examination of the body was made on the following day, with a view to ascertain the immediate cause of death, which, from its extreme suddenness, some had attributed to an impediment at the heart. It was found, however, that such was not the case, but that there was abundant ground

for the opinion that the vessels of the brain had experienced an excessive and sudden distention, without occasioning any rupture or consequent extravasation of blood.

In the following week his remains were followed to their last resting-place, at All Saints' Church, Upper Norwood, by his relatives and friends, as well as by the Principal and Professors of King's College, and by a considerable number of the students of his Class, who, notwithstanding the distance of Norwood from town, and the early hour appointed for the funeral, voluntarily attended to show their respect for the late Professor.

In person, Professor Daniell was tall and large, with a remarkably fine head and bust. His countenance, and indeed his entire mien, betrayed the natural frankness and goodness of his disposition. He looked the English gentleman,—and all his actions proved that he possessed all the best points of that character to an eminent degree.

His habits of life were remarkably regular and temperate. He went but little into society; and enjoyed himself nowhere so much as in the bosom of his own family, where those who saw him most frequently could best appreciate his many excellencies. In all the relations of life, no one could have been more exemplary; he was at once the father and the brother of his children; he was the sincere, constant, and sympathising friend of those who enjoyed the happiness of his intimacy, to whom his removal has left a blank, which can scarcely, if ever, be filled.

The general character of his mind was powerful rather than brilliant,—vigorous and profound, rather than ready or striking. His manner was extremely modest and unassuming, to a degree in some cases almost amounting to diffidence,—so that a slight nervousness always attended him

when he had to speak in public; and he used frequently to say that he never gave the first lecture of his annual course without experiencing a degree of excitement nearly as great as that which he felt the first time he addressed a public audience.

His mode of lecturing naturally took its tincture from the prevailing habits of his mind; and hence his style was sound, rather than brilliant, and his diction forcible and expressive, rather than easy or flowing. He was remarkably fertile in his experiments; and his contrivances for illustration were generally marked by great ingenuity and happy adaptation to the object in view. He often regretted that his education had been so exclusively classical, and used to lament his want of knowledge in the higher branches of mathematics—a want which frequently, in solving the problems required by his investigations, cost him much time and trouble, which a little routine knowledge would have spared. The remarkable clearness of his views, and precision of his habits of thought, however, generally speaking, enabled him to surmount difficulties which would otherwise have often arrested his progress. The turn of his mind was eminently practical; and the habits of business he acquired in early life, and his extensive intercourse with men in general, added to his natural perspicacity, gave him a clear insight into character, and conferred on him advantages which men of science in general do not possess. He possessed a rare union of great intellectual powers with the highest qualities of the heart, which gave his opinions singular weight; and caused his judgment to be very much valued by his colleagues at King's College, as well as by all who were brought into frequent contact with him in scientific or professional pursuits.

We cannot conclude this Memoir more appropriately than by quoting the following brief description of Mr. Daniell's character, from the pen of that valued friend*, who, on the Sunday after he had committed his mortal remains to the tomb, thus concluded his address to the congregation assembled at the Church of All Saints, Norwood.

"In him we see one foremost in the ranks of science, not turning away in disdain from 'the foolishness of preaching,' but bending the great powers of his mind to exhibit Philosophy as the handmaid of Religion, establishing 'the truth as it is in Jesus.'" "He was recently our neighbour, our companion, our friend,—respected, valued, beloved among us. By the inscrutable appointment of Providence, he has been removed from us, and in a manner so awfully sudden, that as we lay him down in the grave with the exclamation, 'Alas! our brother,' we naturally inquire, with the earnestness of affection, was he prepared for this change? Were the rare gifts and qualities which we knew him to possess, his high intellect, his sound good sense, his singleness of purpose, his inflexible integrity, his candour and generosity, his large benevolence, his kindness of manner, his sweetness of disposition,—were they no more than the manifestation and products of this world's wisdom? or were they sanctified by the Spirit,—the graces of a Christian? The question has already been answered in his own eloquent words, which I have so largely quoted†." "While seeking only to teach us, and to use his talents as best he could in the service of his Master, he has undesignedly shown us the source from which all that we most

* The Rev. Edmund Harden.

† From a paper on Clerical Education in the *British Magazine* for 1st January, 1844.

valued and loved in him derived its greatest lustre. A long acquaintance with him, in his social and domestic life, would enable me to add many instances in confirmation of what is here said. But I forbear; not because I might excite a suspicion of the partiality of friendship, but because it would seem almost like a trespass upon the reverence due to the memory of one whose religious character was especially that of humble and unostentatious piety. Had his regular and punctual observance (of the public ordinances of religion) been *all* we knew of him, charity would have interpreted them as fruits and evidences of faith; but associated as they were, to our knowledge, with a consistent life in other respects, nothing but malignity could suggest the possibility of their being the mere formalities of religion. Of him, then, we may be sure, so far as we may presume to express this confidence of any of our fellow-creatures, that his service here was the service of one worshipping God in spirit and in truth, quickening his affections by the outpouring of gratitude for mercies received, strengthening his soul by the exercises of prayer, and seeking wisdom from the Word of God, in the spirit of a little child; 'Of such is the kingdom of heaven.' And as we stand at the grave of our departed brother, the sorrow we feel for our loss is retrieved by the reflection of his gain; and the words which our Church has selected for the comfort of such mourners, come with the gentlest and most soothing influence upon our hearts—'Blessed are the dead which die in the Lord.'"

Whilst these pages were passing through the press, we have had an opportunity of perusing the admirable Address of Sir John Herschel to the British Association, assembled at

Cambridge, from which we extract the following tribute to Mr. Daniell's scientific labours:—

"I cannot quit this subject without reverting to, and deploring the great loss which science has recently sustained in the death of the late Professor Daniell, one of its most eminent and successful cultivators in this country. His work on Meteorology is, if I mistake not, the first in which the distinction between the aqueous and gaseous atmospheres, and their mutual independence, was clearly and strongly insisted on, as a highly influential element in meteorological theory. Every succeeding investigation has placed this in a clearer light. . . . The continued generation of the aqueous atmosphere at the equator and its destruction in high latitudes, furnishes a *motive power* in meteorology, whose mode of action, and the mechanism through which it acts, have yet to be inquired into. Mr. Daniell's claims to scientific distinction were, however, not confined to this branch. In his hands, the voltaic pile became an infinitely more powerful and manageable instrument than had ever before been thought possible; and his improvements in its construction (the effect not of accident, but of patient and persevering experimental inquiry,) have in effect changed the face of electro-chemistry. Nor did he confine himself to these improvements. He applied them: and among the last and most interesting inquiries of his life, are a series of electro-chemical researches, which may rank with the best things yet produced in that line*."

* The President's Address.—*Athenæum*, No. 921, p. 615.

The following list of Mr. Daniell's publications will show the extent of his labours in the cause of science.

METEOROLOGY.

1820 On a New Hygrometer. *Quarterly Journal of Science*, viii. 298.

1819-20-21 Meteorological Journal. *Ib.* vols. ix., x., and xii.

1821 Experiments to ascertain the Effects of the great Eclipse in September, 1820, on the Gaseous and Aqueous Atmospheres. *Ib.* x. 123.

1822 Comparative Remarks (with Three Tables) on the Weather and Seasons of the Years 1819, 1820, and 1821. *Ib.*, xii. 111.

" On the Correction to be applied in Barometrical Mensuration for the Effects of Atmospheric Vapour, by means of the Hygrometer. *Ib.* xiii. 76.

1823 Meteorological Essays. First Edition.

1824 Essay on Climate, considered with regard to Horticulture. *Horticultural Transactions*, 1824, p. 1.

1825 Observations and Experiments on Evaporation. *Quarterly Journal of Science*, xvii. 46.

" On the Horary Oscillations of the Barometer. *Ib.* xvii. 189.

" Observations on the Radiation of Heat in the Atmosphere. *Ib.* xviii. 305.

1826 On the Oscillations of the Barometer. *Ib.* xxi. 82.

" Another Paper on the Barometer. *Ib.* xxi. 230.

" Correspondence concerning the last Paper. *Ib.* xxi. 292.

" On Jones's Hygrometer. *Ib.* xxi. 320.

1827 Second Edition of Meteorological Essays.

1832 On the Water-Barometer erected in the Hall of the Royal Society. *Philosophical Transactions*, 1832, p. 539.

CHEMISTRY, &c.

1816 On some Phenomena attending the Process of Solution, and their application to the Laws of Crystallization. *Quarterly Journal of Science*, i. 24.

1817 On the Mechanical Structure of Iron developed by Solution, and on the Combination of Silex in Cast Iron. *Ib.* ii. 278.

„ On a New Species of Resin, from India. *Ib.* iii. 113.

1818 Observations on the Theory of Spherical Atoms, and the relation which it bears to the Specific Gravity of certain Minerals. *Quarterly Journal of Science*, iv. 30.

„ Correction of Error in preceding Paper. *Ib.* v.

„ On the Strata of a remarkable Chalk Formation in the vicinity Brighton and Rottingdean. *Ib.* iv. 227.

1819 On the Formation and Decomposition of Sugar, and the Artificial Production of Crystallized Carbonate of Lime. *Ib.* xi. 309.

„ On the Acid formed in the Slow Combustion of Ether. *Ib.* vi. 318.

1821 Description of a New Pyrometer. *Ib.* xi. 309.

1822 Inquiry, with Experiments, into the Nature of the Products of the Slow Combustion of Ether. *Ib.* xii. 64.

1830 On certain Phenomena resulting from the Action of Mercury on different Metals. *Journal of the Royal Institution*, i. 1.

1831 On the Relation between the Polyhedral and Spheroidal Theories of Crystallization, and the connexion of the latter with the Experiments of Professor Mitscherlich. *Ib.* ii. 30.

1830 On a New Register Pyrometer for measuring the Expansions of Solids, and for determining the Higher Degrees of Temperature upon the common Thermometric Scale. *Philosophical Transactions*, 1830.

1832 Further Experiments on a New Register Pyrometer for measuring the Expansion of Solids. *Ib.* 1832, p. 443.

1833 On a new Oxyhydrogen jet. *Philosophical Magazine*, vol. ii. 57.

1839 Introduction to Chemical Philosophy. First Edition.

1841 On the Spontaneous Evolution of Sulphuretted Hydrogen in the Waters of the Western Coast of Africa and of other Localities. *Philosophical Magazine*, July, 1841, vol. xix. No. 121, p. 1.

1843 Second Edition of the Introduction to Chemical Philosophy.

ELECTRICITY.

1836 On Voltaic Combinations (the Constant Battery.) *Philosophical Transactions*, 1836, p. 107.

1836 Additional Observations on Voltaic Combinations. *Ib.* p. 125.

1837 Further Observations on Voltaic Combinations. *Ib.* 1837, p. 141.

1838 Fourth Letter on Voltaic Combinations. *Ib.* 1838, p. 41.

1839 Fifth Letter on Voltaic Combinations, with some Account of the Effects of a Large Constant Battery. *Ib.* 1839, p. 89.

„ On the Electrolysis of Secondary Compounds. *Ib.* 1839, p. 97.

1840 Second Letter on the Electrolysis of Secondary Compounds. *Ib.* 1840, p. 209.

1842 Sixth Letter on Voltaic Combinations. *Ib.* 1842, p. 137.

„ Letter to Mr. R. Phillips on the Constant Voltaic Battery. *Philosophical Magazine*, xx. 294.

„ Another Letter on the same subject. *Ib.* xxi. 421.

1844 Additional Researches on Electrolysis. *Philosophical Transactions*, 1844, p. 1.

METEOROLOGICAL ESSAYS.

ESSAY I.

ON THE CONSTITUTION OF THE ATMOSPHERE.

INTRODUCTION.

MAN may with propriety be said to be a meteorologist* by nature: he is naturally placed in such a state of dependence upon the atmospheric elements, that to watch their vicissitudes and anticipate their disturbances, becomes a necessary portion of the labour to which he is born. The daily tasks of the mariner, the shepherd, and the husbandman, are regulated by meteorological observations; and the obligation of constant attention to the changes of the weather, has endued the most illiterate with a certain degree of prescience of some of its most capricious alterations. Nor, in the more refined classes of society, does the subject lose any of its universality or interest: much of the tact of experience, indeed, is blunted or lost: but science furnishes artificial aids to observation, which supply, perhaps inadequately, the deficiency; and the general influence of atmospheric phenomena is still felt

* Meteorology, from μετέωρος, *sublimis*.

and acknowledged, though possibly not so accurately appreciated. The generality of this interest is, indeed, so absolute, that the common form of salutation amongst many nations is a meteorological wish, and the first introduction between strangers a meteorological observation.

But although atmospheric phenomena have excited the attention of all classes of men, from the earliest ages of the world; and have probably formed the most ancient and universal theme of conversation and speculation, both with the learned and unlearned; and although they may have been, daily, nay hourly, discussed since the time when the human race were first exposed to their influence; the remarks of the vulgar, many of which become in the course of ages proverbial, and the theories of the philosopher, have been alike insufficient for a rational and satisfactory explanation of their general laws. Many and ingenious are the instruments which the science of modern ages has constructed for the accurate appreciation of the perpetual changes of the weather; and diligent have been the observers who have dedicated their time to the science of meteorology: but, from the first contrivance of the barometer to the present day, the great and unceasing fluctuations of the vast aërial ocean, denoted by that instrument, are unexplained. The complication of the processes carried on in the immense laboratory of nature, the wide-extended circle of their agency, and the ever-varying results of their compound influences, appear to have been too much for the mind to comprehend as a whole; and the

powers of reason have been bewildered in the inextricable labyrinth of causes and effects; of actions and reactions.

Being deeply interested in the investigation of the forces which concur to the production of meteorological phenomena, and having devoted much of my time and attention to experimenting upon the subject, it occurred to me to consider, that although the science of Meteorology, contemplated as a whole, had lately made but little progress, yet, that the parts of which it is composed, constituting nearly the whole circle of the natural sciences, had been by no means stationary; but, on the contrary, were making rapid strides towards perfection. The elements of the science, considered as founded upon experiment and observation, have been largely extended and deeply explored; and a rich accumulation of facts has been collected, which only require, perhaps, to be properly adjusted, to enable us to raise the superstructure with security. I reflected that, in the present state of our knowledge, this might probably be done *synthetically* with the greatest advantage; and that by setting out from a few plain and established principles, and by accurately appreciating their mutual influences, there was a probability of ascending with security to more complicated relations; till at length, by gradual structure, we might possibly accomplish the explanation of those atmospheric phenomena, the analysis of which has hitherto been perplexed with insurmountable difficulties. This idea has been so strongly impressed upon my mind, that I have resolved to institute such a pro-

cess, and with this clue, to venture in a path in which so many have failed before me.

Before I proceed, however, to attempt the solution of the problem thus contemplated, it may not be improper to prove the necessity of further illustrating a subject which has already exercised the ingenuity of so many and such distinguished philosophers. I will not stop to refute the utterly untenable, but still popular, opinions regarding the changes of atmospheric pressure which refer them either to the generation and destruction of inflammable gases in the upper regions of the atmosphere, or to the variable amounts of aqueous vapour in its constitution, but will refer to one of the latest hypotheses upon the cause of the rise and fall of the barometric column: namely, that which was advanced by Professor Leslie*. This distinguished philosopher, previous to offering a solution of the difficulty, passes a sentence upon the attempts of all those who had preceded him in the task, with which the scientific world in general will be disposed to agree.

"Philosophers have eagerly sought to explain the fluctuations of the mercurial column. They have tried every principle that might appear to exert any influence in modifying the local weight of the atmosphere; but their very numerous attempts, it must be confessed, have hitherto proved singularly unsuccessful. It was requisite to show that such causes would not only give results of the kind expected, but were, besides, fully adequate to the production of the phenomena.

* *Ency. Brit.* Article METEOROLOGY.

In most instances, however, either none of those effects could have followed, or they would occur in a very inferior degree and disproportionate extent."

The principal of these attempts he then proceeds to examine; and having shown their fallacy, propounds the following explanation, as hitherto overlooked, and capable of furnishing a satisfactory solution of a great variety of phenomena.

"It is obvious that a *horizontal* current of air must, from the globular form of the earth, continually deflect from its *rectilineal* course. But such a deflection, being precisely of the same nature as a centrifugal force, must hence diminish the weight or pressure of the fluid. The only question, is, to determine the amount of that disturbing influence. Though it should appear quite inconsiderable in the interval of a short space, it may yet accumulate to a very notable quantity through the wide extent over which the same wind is known to travel. Suppose a current to begin to flow from A, fig. 1,

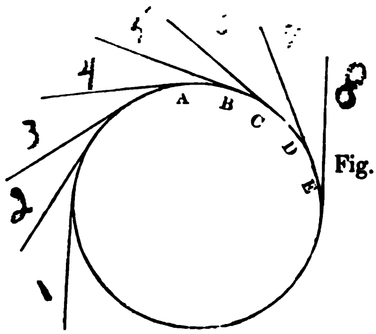

Fig. 1.

in the direction of a tangent, it will successively bend from a rectilineal track at the points B, C, D, &c., on

the surface of the earth. The particles of the fluid are, therefore, drawn incessantly from their course by the action of gravity. Their vertical pressure is consequently diminished by the force spent in producing this deflection. Wherefore, during the prevalence of the wind, the atmospheric column will press with inferior weight at B than at A, at C than at B, at D than at C; thus gradually decreasing through the whole chain. Suppose the intervals A B, B C, C D, D E, &c., to be each of them a mile, and that the current reaches the points B, C, D, E, &c., in successive minutes, a celerity which frequently happens; the deflection at B, owing to the curvature of the earth, would be eight inches, or two-thirds of a foot; but the space through which a body would descend in a minute, by the action of gravity, is $60 \times 60 \times 16 = 57,600$ feet, or 86,400 times greater than the deviation from the tangent. Wherefore the atmospheric pressure would, on that hypothesis, be diminished by the 86,400th part for each interval of a mile from A to D. In the space of 288 miles, this diminution would consequently be the 300th part of the incumbent weight; and over an extent of 2880 miles, it would amount to the 30th part. If we assume the very probable estimate, that storms involve the whole region of the clouds, or attain an elevation of near three miles, the diminution of pressure, occasioned by a long series of deflections in the stream, would affect one-half of the atmosphere. Wherefore a wind which has been blown over a tract of 2880 miles at the rate of 60 miles an hour, might cause the mercurial column to subside half an inch.

If the velocity of the wind were doubled, which is probably the limit of the most tremendous hurricane, the fall of the barometer would be four times greater, and amount to two inches."

Now I conceive, that it will be no very difficult task to show that the Professor has been as unfortunate as his predecessors, in his proposed solution: and nothing can better illustrate the difficulty of the problem than such a failure. His error appears to me to lie in the misapplication of the term *horizontal*, in the first sentence of the above extract: as there applied, it is made to signify *rectilineal*, contradistinguished to parallelism to the surface of the globe. Now what power can be supposed to produce such horizontality as this? Sir John Leslie observes, that deflection from it is "of the same nature as a centrifugal force:" but is it not obvious that it is itself a centrifugal force? And whence then does such an impulse originate? He has not revealed to us the manner in which he supposes the wind, which he employs, to arise, (and this alone is a defect in his theory;) but upon no known principle, I conceive, can its tendency be tangential to the circumference of the earth. But, granting for a moment, the possibility of such a direction, let us suppose a current to begin to flow from A, in the direction of a tangent, and that it is bent from its rectilineal track at the point B by the action of gravity, how is the unknown force to be renewed, so that the wind at B is again to assume a tangential course? But the hypothesis not only supposes this, but further, that it is infinitely renewable; and the

effect which is at first scarcely perceptible, is "accumulated by a long series of deflections."

The foundations of this theory are, as I think, palpably erroneous; and if such be the case, it can scarcely be necessary to remark that, the accordance of the phenomena with it has not been so close as was supposed: indeed many inexplicable cases can be adduced to prove its insufficiency. One of the strongest of these is, that wind does not always precede a fall of the mercurial column; but, on the contrary, the greatest depressions of the mercury generally precede a wind. Sometimes also great falls are not attended with wind, and sometimes, the mercury has been depressed to leeward of the storm.

It is the more singular that Professor Leslie should have propounded this theory, as, in referring in his treatise to a well-known experiment of Mr. Hauksbee, made at the beginning of the last century, he establishes its fallacy in a way which is equally applicable to his own hypothesis; if, indeed, it be not the very same idea, clothed in another dress.

"To explain," says he, "the descent of the barometer during wind, a very ingenious idea has been proposed, which, being apparently confirmed by experiment, has obtained general reception. It is conceived, that a current of air, in sweeping over the surface of the earth, must cease to exert any vertical pressure. But this assumption can hardly be reconciled with any strict principle in science, *for the particles of air will not for a moment cease to gravitate, nor will any horizontal motion of them produce the slightest*

derangement in a perpendicular direction." Now the tangential direction of Mr. Leslie's wind, is nothing less than a *cessation to gravitate;* and its horizontal motion produces *derangement in a perpendicular direction,* in violation of the very law which he has himself so properly and carefully explained.

M. Biot, again, another of the great masters of science, after adverting to the different hypotheses which have been framed for the explanation of the motions of the barometer thus candidly concludes his review of them all:—

"Le parti le plus sage est de considérer ces faits comme des résultats d'observation dont on ne peut jusqu'à présent donner aucune explication satisfaisante. La hauteur du baromètre éprouve des élévations et des abaissemens qui paraissent ténir aux modifications de l'atmosphere mais dont la cause est encore inconnu*."

Mr. Kaemtz has very recently proposed the following explanation of the barometric oscillation. "When the barometer falls in a country, it is because the temperature of this country is higher than that of the neighbouring countries, whether because it is heated directly, or because these countries are cooled; on the contrary, the rise of the barometer proves that this country becomes colder than those which surround it." He also states that the barometer is analogous to the differential thermometer; "it points out to us the differences of temperature between two places situated at great distances."

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* *Traité de Physique*, tom. i., p. 95.

Now that there is a most intimate connection between the fluctuations of the atmospheric temperature and pressure cannot be for a moment doubted; but that it is not of the simple nature above pointed out, will, I think, appear from a careful comparison of observations. The changes of temperature which chiefly affect the barometric pressure take place in the heights of the atmospheric strata, and cannot be measured alone by thermometers placed near the surface of the earth, as I shall endeavour to show in the sequel.

Let us, however, proceed to rear the scaffold by which we may hope to place this phenomenon in its proper connection with others, so that they may mutually support and illustrate each other.

PART I.

REVIEW OF THE PHYSICAL FORCES CONCERNED IN ATMOSPHERIC PHENOMENA.

THE atmosphere (ἀτμὸς σφαῖρα), the sphere of vapour;—that is, the terrestrial sphere of matter in its elastic, fluid, state, which rests and presses upon the solid and liquid surface of our globe, constitutes the province of Meteorology. We may regard it as a domain which has hitherto been but irregularly explored; of which we possess, indeed, much valuable information, but no connected survey, no scientific map. It is our purpose to attempt an outline of such a map from observations which abound on every side, which may be to the science what the rough delineations of the first explorer of an unknown country are to the surveyor by whom he is succeeded. As in the map of Africa; the frequent recurrence of "unexplored regions" may direct explorers whither they may most profitably turn their energies.

Before we set out upon our task, let us, however, endeavour to attain some definite and correct notions with regard to the extent of the aërial ocean, for incorrect estimates are generally formed of its relative dimensions.

The lower surface of the atmosphere is equal to about 200,000,000 square miles, and if it were every where of the same density as at this surface, its entire

height, as we shall presently show, would not exceed five miles; but as it decreases in density in a geometric progression for equal heights, it expands to an amount which various considerations prove not to exceed fifty miles. Thus the proportion of the thickness of the atmosphere to its superficial extent cannot exceed that of 1 to 4,000,000: such high numbers, however, produce but little impression upon the mind, and perhaps a clearer notion will be formed of the fact by stating, that this is only equal to one five-hundredth of the proportion which the sheet of paper which is pasted upon a twelve-inch globe bears to the surface of that globe. It is within a tenth part of this depth, or one five-thousandth part of the comparative thickness above referred to, that all the phenomena occur to which we are about to direct our attention. It is clear that such a thin envelope must primarily follow all the motions of the denser surface over which it is diffused.

The first aspect of our subject of investigation is, perhaps, that of simplicity: the common observer sees nothing in the medium by which he is surrounded but a homogeneous fluid; agitated, indeed, at times, by causes to him unknown; upon which clouds of vapour float and through which the rain descends; but because they do not directly affect his senses, he is unconscious of processes of extreme complexity, and of the agency of highly energetic forces, which never for a moment suspend their operation. The constitution of the atmosphere is, in fact, very complex, and the forces which constitute the main springs of its motions and

disturbances not such as fall under the observation of common experience.

The science of Meteorology, as has been already stated, must be founded upon the general principles of Physics; and although it will be necessary to take for granted in the student a general acquaintance with the laws which regulate the action of different forces upon matter, it may promote our object to recall briefly their relations to that peculiar state of matter which is to form the principal object of our discussion. We will do this under the heads of the different forces which are called into action. The principal of these are, the antagonist powers of Gravity and Heat, which, acting upon the weight and elasticity of the atmosphere, excite and maintain all its complicated movements.

1st. Gravity. Although mankind were long in possessing themselves of the truth with any degree of clearness, it is now generally understood that *the air has weight.* Without recapitulating the evidence of the fact derived from experiments with the air-pump, it may be sufficient to state that the most accurate determination makes the weight of 100 cubic inches of dry, pure air, at the temperature of 60° and under a pressure of 30 inches of mercury, 31·0117 grs., being for a cubic yard something more than four ounces and a half. It has been calculated that the total weight of the atmosphere is equivalent to 3448 cubic leagues of quicksilver.

From its constitution as a *fluid* it will, when confined, communicate pressure in all directions alike, and,

when unconfined, flow from the point of greatest to that of least pressure. The velocity of air of standard temperature and pressure rushing into a vacuum would be something more than 1300 feet in a second of time, or about 15 miles per minute.

From its constitution as an *elastic* fluid, its volume is always inversely proportioned to the pressure upon it: its elasticity directly as the pressure.

In the unconfined atmosphere its own weight is its compressing force, and, as in ascending from the surface of the earth we diminish the length of the compressing column, the weight and elasticity of equal volumes must decrease as we ascend. The difference of elasticity in a height of even six feet may be made manifest experimentally.

2nd. Inertia. The air possesses inertia in common with other ponderable bodies, and can neither acquire nor lose *motion* without the communication or opposition of force.

The *momentum* of air, which is one of its properties out of the line of common observation, and which, although of extreme importance in atmospheric fluctuation, has been much overlooked, may be strikingly illustrated by a simple experiment. Place three lighted tapers in a row at a distance of three inches apart; if we now set the small volume of air in an unloaded gun in motion by means of the percussion powder of one of the common priming caps, and direct the gun at the distance of ten feet towards the centre flame, it will be blown out without the slightest dis-

turbance to the contiguous flames. Another beautiful illustration of the momentum of air and the facility with which a rotatory movement may be communicated to it is derived from the bursting of any air-bubble in the atmosphere, accompanied by smoke or steam, by which the motions may be rendered visible. Bubbles of phosphuretted hydrogen are best adapted to this purpose on account of the dense smoke of phosphoric acid which is produced by their spontaneous combustion. The beautiful wreaths which are thus produced are well-known phenomena; but it has not been so generally observed that the whole circumference of each circle is in a state of rapid rotation in a vertical direction; it being this rotation, in fact, which confines the smoke within its narrow limits and causes the circles to be so well defined. The same phenomena may often be observed in the bursting of steam bubbles, or of those of oxygen and hydrogen rising in a large voltameter; and they may be observed very frequently upon a large scale in the firing of ordnance on a still day. Any force acting suddenly upon the air from a centre throws it into rotatory motions. Similar rotating wreaths of great beauty may be produced by means of a tin funnel, over the wide mouth of which a thin membrane has been tightly stretched. The interior must be filled with smoke, from ignited brown paper or other means, introduced at the small aperture. A slight blow upon the centre of the membrane will be sufficient to project the wreaths.

The momentum of air is also commonly exemplified

on a large scale by its conversion into mechanical force by the sails of ships and wind-mills.

3rd. MECHANICAL FORCE. Air is perfectly obedient to mechanical force, and may be set in motion with the greatest facility. It accurately obeys the laws of motion common to all ponderable bodies, and its *momentum*, or the quantity of force which it is capable of exerting upon other bodies opposed to it, is estimated in the same way by multiplying its weight by its velocity.

4th. HEAT. The relations of heat to aëriform matter are numerous, and, with regard to the phenomena of the atmosphere, of primary importance. We can here only briefly advert to them.

Radiant Heat, speaking generally, passes through perfectly-transparent air with little obstruction; it has however been calculated that about one-fifth of the solar heat is absorbed by passing through 6000 feet of the atmosphere in its purest state.

The late investigations of M. Melloni have proved that there are specific differences in radiant heat which occasion differences of transmission, absorption, and secondary radiation by different media. The action of atmospheric air upon these different rays is but little known, but there is no doubt that the properties of those which are transmitted to the surface of the earth are different from those which are first absorbed*. Of the radiating power of the atmosphere

* See the Essay upon Radiation.

itself into space we know absolutely nothing; but questions of great interest to Meteorology are involved in these obscure actions.

Temperature. Aëriform bodies are the worst *conductors* of heat with which we are acquainted; the amount of heat which can pass from particle to particle without disturbance of the relative position of the particles being scarcely appreciable. On the other hand, their perfect fluidity and their great powers of expansion render them most efficient *conveyers* of heat.

In order effectually to raise the temperature of a large mass of air the heat must be applied to its lower part; in which case processes of circulation will be immediately established which are in general but little understood, although it is of importance clearly to distinguish them in the phenomena which we are about to examine. Their mechanism, if the expression may be allowed, is curious and complicated. It is perpetually presented to our observation in the effects of artificial fires by which we are constantly surrounded, the smoke from which marks the progress of its operation.

Heated air does not rise in a vertical current as when confined in a chimney, but is broken into whirls and eddies which rotate rapidly in differently inclined planes, opening out and expanding as they are borne away by the prevailing current in which they are formed. By these circular and rolling motions the heated air becomes thoroughly and rapidly blended with the cooler; and the mixed mass, from its expansion, gradually and slowly rises, but exhibits

signs of broken circumvolutions as long as a portion of smoke remains dense enough to indicate its motions.

An extemporaneous experiment upon the subject may be made with a wax taper recently extinguished, the glowing wick of which will emit smoke enough to indicate these gyrations in a very pleasing manner. In an undisturbed atmosphere the circles are formed with almost perfect precision, and maintain their forms while they expand for a long time. When broken by any cross current they form new whirls of less regularity, and the last fragments of the broken and faded wreaths will be found moving in curvilinear paths.

The descent of cold or dense gases into a lighter medium is accompanied by similar phenomena, as is well seen by the condensed moisture when a bottle of hydro-chloric, or fluo-silicic gas is emptied slowly into a still atmosphere.

This rolling motion is produced by the mutual friction of the hot and cold particles of air, and its energy is probably in proportion to the square of the relative ascensional force*. Even non-elastic fluids move in certain curves to avoid minute obstacles; as may be observed by the motion of particles suspended in a stream of water.

Heat becomes equally diffused by this kind of gyratory convection through large masses of the atmosphere, which then place themselves in equilibrio with more distant masses, by breaking into opposite self-compensating currents.

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* Young, ii. 61.

Both the processes which we have thus endeavoured to describe may be simply illustrated by placing a lighted taper in a flat dish and covering it with a bell-glass furnished with a long chimney, the latter being placed immediately over the flame. If a little water be poured into the dish, the air will be prevented from entering under the edge of the glass, and the taper will be speedily extinguished for want of a fresh supply. The gyratory movements of the hot and cold air as they mingle will be seen, by the smoke, to be confined to the wide glass, the narrow space of the chimney being insufficient for their development. The mutual friction, moreover, of the hot air tending to rise, and of the cold air to descend, effectually prevents the egress of the one and the ingress of the other through the chimney. If, however, the chimney of the bell-glass be divided into two channels by a diaphragm down the middle, and the lighted taper be replaced in its former position, it will continue to burn for any length of time. By this arrangement the mutual interference of the hot and cold currents is avoided, for the hot air will pass out by an ascending current on one side of the diaphragm, and the cold fresh air will descend in a contrary current on the other side, and the two will just compensate each other.

The amount of the expansion of aëriform fluids for every degree of Fahrenheit has been determined to be in all cases the $\frac{1}{480}$th part of the volume* which they

* According to the recent experiments of Rudberg, the expansion is $\frac{1}{493}$rd of the volume at 32°.

occupy at the freezing point of water. When confined in a space where this expansion cannot take place their elasticity is increased in the same proportion for the same accession of temperature.

If the elasticity of a body of air in motion tend to rise or fall in consequence of a change of temperature, its velocity will be augmented or decreased according as the impulse agrees with its direction or not.

The *Specific Heat* of air of standard temperature and elasticity compared with an equal weight of water is as 1 to 0·2669; but it is inversely proportioned to its compression, so that air by rarefaction absorbs its own sensible heat and becomes cooled, and by condensation evolves it and is heated. Professor Leslie, after an able investigation of the subject, has given a formula for the calculation of these changes, which has been found to agree with experiment throughout a great range of densities. In ordinary language it is as follows: Multiply the constant number 45 into the difference between the density of the air and its reciprocal, and the result will represent the measure of heat on Fahrenheit's scale due to the change of condition.

The extreme facility with which atmospheric air absorbs and emits the proper specific heat which is due to any change in its density, is curiously illustrated by a well-known phenomenon of sound. The inquiry into the cause of sound had led to conclusions respecting its mode of propagation, from which it was supposed its velocity in air could be precisely calculated. Upon making the calculation, however, it was found that the whole velocity could not be shown to arise from this

theory. There was still a residual velocity to be accounted for, which placed philosophers for a long time in a great perplexity. At length Laplace made the happy suggestion that this might arise from the *heat* developed in the act of that condensation which necessarily takes place at every vibration by which sound is conveyed. The matter was subjected to exact calculation, and the result was at once the complete explanation of the residual phenomenon, and a striking confirmation of the general law of the development of heat by compression under circumstances beyond artificial imitation*.

The preceding observations apply to atmospheric air considered as homogeneous in its constitution; but this is far from being the case, and it must now be regarded as a mixture of different *kinds* of matter in the elastic state.

And here we must recall the distinction between gases and vapours; for the vapour of water at all times forms an important, but variable part of the atmospheric mixture. It is true that, since the discoveries of Dr. Faraday, this distinction may be looked upon as one of degree and not of constitution, and that all gases may be regarded as the vapours of liquids far below the elasticity which would constitute their boiling points. Their points of condensation, however, never fall within the range of atmospheric phenomena, and the difference of their relations to heat is marked and essential to observe.

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* Herschel.

The vapour of water, or steam, when not in contact with its generating liquid, expands from increments of temperature according to the same law as dry air. It contracts also by the same law on cooling, till it reaches its constituent temperature; below which it is reduced to water and vapour of such inferior elasticity as may be supported by the lower degree. Any mechanical pressure tending to give it an elasticity beyond that which is due to its constituent temperature, will also cause its condensation. When in contact with water, every increase of temperature not only causes it to expand, but increases its volume, its elasticity, and its density, by the process of evaporation.

Latent Heat. The *specific heat* of aqueous vapour, compared to an equal weight of water as 1, is 0·8470, or more than three times that of dry air; but the most important consideration is that of the heat which is *latent* in its constitution, and becomes free upon its condensation. This in round numbers amounts to 1000°, or more accurately, when added to its sensible heat at any temperature, makes up the sum 1130°. Thus the heat evolved by the condensation of a given weight of steam would raise the temperature of 1000 times its weight of water 1°, or, having regard to the difference of specific heats, 1000 times its weight of air, 3°·7.

5th. HETEROGENEOUS DIFFUSION. It is probable that atmospheric phenomena are wholly independent of the action of chemical affinity in the strictly-limited

sense of the term, but that kind of action by which the dissimilar particles of different kinds of gases and vapours become intimately and uniformly blended together, notwithstanding the greatest differences of specific gravity, it is of the utmost importance to consider.

The permanent gases of the atmosphere are nitrogen, oxygen, and carbonic acid. The first two are always found in the nearly unvarying proportion of 80 per cent. of the former, and 20 per cent. of the latter. The carbonic acid varies even in the same place within short intervals of time. It amounts, according to the best analysis, to 6·2 parts as a maximum, and 3·7 parts as a minimum, in 10,000 parts.

Dr. Dalton was the first to put forth the conception that the mixture of gases depends upon their acting towards each other as *vacua;* and the same physical considerations which lead to the conclusion that the velocity with which atmospheric air considered as homogeneous would rush into a vacuum, would something exceed 1300 feet in a second of time, prove also that the velocity of different kinds of gases under similar circumstances, would be *inversely as the square roots of their densities.*

Professor Graham has experimentally measured the diffusive power of different kinds of gases, and the form of his experiment admirably illustrates the nature of the process by which the mixture of gases is effected. The apparatus which he employs he has named a *diffusion tube.* It is simply a graduated tube closed at the upper end by plaster of Paris, or some other porous substance. When such a tube is care-

fully filled over water, with hydrogen gas for instance, the closed end being kept dry, the gas immediately begins to flow through the pores, and diffuse itself in the air, and that with such velocity, as to draw up after it a column of water of considerable height. The rise of the water commences immediately, and forms a very striking experiment. In a tube fourteen inches long, it will ascend six or eight inches in as many minutes. The atmospheric air tends also to pass in the opposite direction, and as the elasticity of the air in the tube diminishes, it is gradually forced through the pores by the mechanical preponderance of the exterior pressure, and puts an end to the escape. In accurate experiments this is guarded against by gradually sinking the tube in the water-bath so as to maintain the water in the interior at the same level as at the exterior. The process of diffusion which commonly takes place in an insensible manner, is thus rendered sensible to the eye.

The process may be rendered still more striking by closing the aperture of a wide-mouthed phial with a film of the lather of soap and then covering the phial with a jar of protoxide of nitrogen. In the course of a few seconds the horizontality of the film will be disturbed; it will become convex, and at the end of a minute and a half or two minutes, it will form the greater part of a sphere of two inches in diameter. Gases thus pass through films of water with extreme rapidity, and the motion only ceases when the mixture on each side of the barrier becomes similar in composition.

This process of diffusion can only take place between the heterogeneous particles of dissimilar fluids, and is very different from the process of circulation by which the temperatures of unequally heated fluids become equalized; the latter is purely mechanical, or *massive*, and the currents which are produced may be detected by the transport of light materials in their courses; the former is chemical, or *molecular*, and it is incapable of transferring its force to masses of matter.

By experiments with the diffusion tube, Professor Graham was led to the conclusion that each gas has a diffusiveness peculiar to itself, which is greater as its density is less, being *inversely proportional to the square root of the density of the gas.* Here, then, we have the same law which is derived from the consideration of the gases flowing into a vacuum.

Dr. Dalton, to whose clear views upon this subject science is greatly indebted, did not mean to assert that the process of diffusion takes place with the same velocity as if the gas were to pass into a real vacuum; because the particles of one gas, he conceived, afford a mechanical impediment to the progress of another, but that the ultimate result is the same. Neither do the experiments of Professor Graham determine the absolute rate at which one gas will travel through the pores of another, but only that the rate will be inversely proportional to the square root of the density.

The importance of this mechanism by which gases rapidly permeate each other's texture and become equally diffused, it is scarcely possible adequately to appreciate. The welfare of the whole organic creation

depends upon the due maintenance of the proportions of the several aëriform fluids of which the atmosphere consists. The processes of respiration and combustion are perpetually tending to destroy those nicely-adjusted proportions, by the abstraction of the vital air and the substitution of carbonic acid, which is a deadly poison to animal life, and yet by the simple means which we are considering, the poisonous air is not allowed to accumulate, but diffuses itself rapidly through space, while the vital gas rushes by a counter tendency to supply the deficiency which the local consumption has created. Hence the invariable uniformity of this mixture; which is such that the most accurate analyses of the most eminent chemists have failed to detect any material difference in the proportion of oxygen in air taken from localities the most opposed to each other in all the circumstances which might be supposed to affect its purity.

The spontaneous evaporation of water, and the diffusion of steam through the air, take place doubtless by the same process; and the independence of the aqueous atmosphere is in fact proved by the invariableness of the depression of temperature produced by the evaporation from the surface of any moistened porous body in an atmosphere of any given degree of dryness. The amount of this depression depends solely upon the temperature and the dew point; and although the amount of evaporation in a given time is greatly affected by the density and motion of the gaseous medium, the temperature of the evaporating surface, and the tension of the rising vapour, are go-

verned entirely by the elastic force of the steam previously intermingled with it.

We have several facts which bear upon the point of the obstruction which dry air offers to the diffusion of aqueous vapour. In an atmosphere of the elasticity of 30·4 inches of mercury, kept perpetually dry by the absorptive power of sulphuric acid, evaporation has been found to proceed at the rate of 1·24 grains in half an hour, from a circular glass 2·7 inches diameter, at the temperature of 45°. This evaporation was found to vary in inverse proportion to the elasticity of the incumbent atmosphere*. It is also known to increase with the velocity of the wind which passes over the evaporating surface, though no exact measure has been obtained of this effect. Dr. Dalton found that the rate of evaporation which took place in the open air in a calm, *ceteris paribus*, was increased one-half by a high wind.

It is obvious that the rate of evaporation will be diminished in proportion to the elasticity of any vapour already existing in the air, and the rapid motion of the wind carries off and disperses the vapour which would otherwise linger upon the surface and obstruct the process. It, in some measure, acts the part of the sulphuric acid in the experiment referred to.

6th. ELECTRICITY. The permanent gases of the atmosphere are *dielectrics*, and the most perfect insulators, or the worst conductors of electricity, with which

* See the Essay upon Hygrometry.

we are acquainted: nevertheless, their particles are capable of changing their usual polar state for a state of absolute charge under the influence of other charged matter, and may then circulate between two oppositely electrified surfaces with considerable velocity and momentum.

Perfectly *dry* vapour is probably not inferior to the permanent gases in its insulating powers, but in the moment of its condensation it becomes a conductor, and is capable of greatly lowering the insulating power of gases with which it may be mixed even in invisible proportions.

The subject of atmospheric electricity is only now beginning to excite that degree of attention amongst scientific inquirers which its importance deserves, and cannot be introduced with any advantage into the preparatory view which we are contemplating of the domain of meteorology. The experiments, however, of M. Peltier, and the theory of electrical induction recently established by Dr. Faraday, have suggested new views of atmospheric phenomena of this class, and indicate methods of observation and experiment which promise to be more efficacious than those which have been hitherto adopted, and of which we shall endeavour to give some account in a separate Essay*.

Now these fundamental principles which have been thus recapitulated, as most immediately applicable to the investigation upon which we are about to enter,

* See the Essay upon Atmospheric Electricity.

are the fruits of a long, laborious, and accurate METHOD OF INDUCTION, carried on, in different branches of physical science, through a vast period of time by a succession of the most eminent philosophers. Setting out from them, it appears to me that the DEDUCTIVE METHOD may be most advantageously applied to the gradual developement of the complex phenomena of the atmospheric ocean. Let us therefore endeavour to determine from the laws of the forces thus established, what effects any given combination of these causes will produce.

In adopting this method, I shall divide the proposed inquiry into four sections. In the first, I shall consider the habitudes of an atmosphere of perfectly-dry, permanently-elastic fluid, under certain conditions; in the second, those of an atmosphere of pure, aqueous vapour; in the third, the compound relations of a mixture of the two; and in the fourth, I shall endeavour to apply such principles as may legitimately be deduced from the previous investigation, to some of the observed phenomena of the atmosphere of the earth. Many of the observations which I shall have to make, will appear, at first, trite and uninteresting; but let it be remembered that it is from self-evident axioms that the most complicated problems are solved.

PART II.

ON THE HABITUDES OF AN ATMOSPHERE OF PERFECTLY-DRY, PERMANENTLY-ELASTIC FLUID.

In putting the following hypothetical cases, my object is to assimilate the conditions as much as possible to those of the atmosphere of the earth; separating only the phenomena into classes, that, in considering each class singly, we may trace, without confusion, the primary effects of each simple cause.

I shall, therefore, propose as the first problem, the natural state of an atmosphere, of perfectly-dry permanently-elastic fluid, surrounding a level sphere in a state of rest, of uniform temperature in all its parts, of the same diameter as that of the earth, to the centre of which it gravitates equally*?

Its height, density, and elasticity, would every where be equal, at equal elevations from the surface; and the column of mercury, which it would support in the barometer, would be the same everywhere at the surface of the sphere. These conclusions rest upon the fundamental laws of hydrostatics, and need no demonstration here. The first condition, therefore, of its state, must be that of perfect equilibrium and rest.

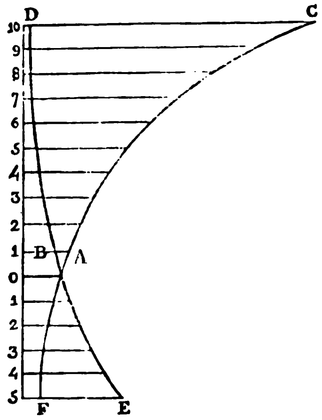
The second condition is, that its density must

* The variation of gravity with the distance from the centre need not be taken into account for the present purpose.

decrease in a geometrical progression, in ascending through equal stages to its higher regions: for the density would everywhere be proportionate to the superincumbent weight.

The calculation of this progression is simple: for in logarithmic curves, such as that by which this progression may be represented*, when the ordinates are the same, the intercepted portions of the abscissæ are proportional to the subtangents, and the process may be conducted in the following manner: We will suppose the length of a column of mercury, at the

Fig. 2.



* The line 0 denoting the natural density of the air at the surface, the line 1 A next above it shows the degree in which the air is expanded at the height of a mile, and 1 B the density of the air at the same height: in the same manner 10 C shows the expansion of the air at the height of 10 miles, and 10 D its density; and 5 E below the line the density which it would acquire at the depth of 5 miles below the earth's surface. The lines A C, D B E, are of the kind called logarithmic curves.

The height of the homogeneous atmosphere, 0,10, is the subtangent of the curve A C, whose ordinates, D C, &c., are as the density of the air at the different altitudes.

surface of the sphere, equivalent to the pressure of an equal column of the air, to be 30 inches, and its temperature to be 32°: the height of an homogeneous atmosphere, of equal density in all its parts, would be 26250 feet, or 4375 fathoms: for the specific gravity of dry air at 32°, and under a pressure equal to 30 inches of mercury, is to that of mercury as 1 to 10500 nearly. From these data the density for any height may be found by the use of logarithms*: for it happens that the height of the homogeneous atmosphere expressed in fathoms is very nearly the $\frac{1}{10000}$th part of the logarithmic subtangent; and, indeed, if we adopt the specific gravity of mercury compared to dry air at 32°, according to the experiments of MM. Biot and Arago, it is almost identical with it. The height according to this determination is 4346 fathoms, which is very nearly equal to $\frac{43429448}{10000}$, or 4342·9448. Therefore, as the height of the homogeneous atmosphere, or atmospheric subtangent, is to the height proposed, so is the modulus of the common system of logarithms, or logarithmic subtangent, to the difference of the logarithms of the densities. Thus, under the conditions just named, let it be required to know the pressure or elasticity of the atmosphere at the height of 5000 feet;

	Feet.	Feet.	Modulus.	Difference.
then	26250 :	5000 ::	·4342945 :	·0827227.

which, deducted from 1·4771212, the logarithm of 30 inches, leaves 1·3943985, the logarithm of 24·797 inches, the height of the mercurial column required.

* See Young's *Natural Philosophy*, Vol. I page 272.

The following Table represents the fall of the barometric column and corresponding decrements of density, for the different heights subjoined.

TABLE I. *Showing the Decrease of Density, and Fall of the Barometer at different Heights in an Atmosphere of uniform Temperature throughout.*

Height in Feet.	Barometer Column inches.	Density.	Temp.
0	30·000	1·00000	32
5,000	24·797	·82656	32
10,000	20·499	·68321	32
15,000	16·941	·53472	32
20,000	14·000	·46677	32
25,000	11·575	·38582	32
30,000	9·567	·31890	32

The temperature being supposed uniform throughout the perpendicular aërial column, this adjustment of density is mechanical only, and is in every part accurately measured by the heights of the mercurial column.

The third condition of the atmosphere must be, that its sensible heat decrease progressively from below upwards. Experiment has proved that the specific heat of atmospherical air, relative to its mass, increases as the density diminishes: the absolute quantity of heat contained in every part of any vertical column remaining unchanged, this gradation of temperature must naturally flow from the enlarged capacity which the air acquires from rarefaction.

The temperature due to any given height, may easily be found by the formula of Professor Leslie, as follows. Reckoning the density of the air at the surface of the sphere, at the temperature of 32° and at a

pressure of 30 = 1, the difference between the density at any given altitude and its reciprocal being multiplied by 45, will express the mean diminution in degrees of Fahrenheit.

For example, the density being inversely as the pressure, 30,000 : 24·697 : : 1·000 : ·826, which is the density at 5000 feet, the density at the surface being 1. Therefore, ·826 : 1·000 : : 1·000 : 1·210, and 1·210 − ·826 = ·384 × 45 = 1·72, the diminution due to that elevation*. The scale of temperature, appropriate to the preceding heights and densities, will then be as follows.

TABLE II. *Showing the Decrease of Density and Temperature due to different Elevations, in an Atmosphere of permanently-elastic Fluid.*

Height in Feet.	Density.	Temperature.
0	1·00000	32·
5,000	·82656	14·8
10,000	·68321	− 3·1
15,000	·56472	− 22·4
20,000	·46677	− 43·6
25,000	·38582	− 67·5
30,000	·31890	− 95·1

These successive temperatures therefore may be considered as equivalent to each other at their respective heights, and perfectly definite for the heights.

But we have here another cause developed, which affects the constitution of permanently-elastic fluids; namely, an alteration of temperature. A difference of 1 degree, upon Fahrenheit's scale, causes, as we have

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* See *Encyclop. Brit.*, Supplement, Article CLIMATE, p. 188.

already stated, a contraction or expansion of $\frac{1}{480}$th part of their volume; which, under equal pressure, proportionally increases or diminishes their specific gravity; or, when confined, raises or depresses their elasticity to the same amount.

From this cause, the barometer alone, will no longer be the exact measure of the progressive density; but for this purpose, its indications must be associated with those of the thermometer. The mercurial column will be shortened $\frac{1}{480}$th of its length at the several stages, for each degree of depression due to the elevation; and its fall for equal altitudes will differ by that quantity from the preceding geometrical progression. The following Table gives the height of the barometer, the specific gravity, and the equivalent temperatures for the scale of heights before proposed.

TABLE III. *Showing the Fall of the Barometer, at different Heights in an Atmosphere, decreasing in Temperature in the preceding Progression.*

Height in Feet.	Barometer.	Sp. Gravity.	Temperature.
0	30·000	1·00000	32·
5,000	23·949	·82656	14·8
10,000	19·106	·68321	− 3·1
15,000	15·229	·56472	−22·4
20,000	12·044	·46677	−43·6
25,000	9·579	·38582	−67·5
30,000	7·566	·31890	−95·1

It must be observed, however, that this refrigeration of the successive strata of the air, which is the consequence of the absorption of their own heat of

temperature, is very different from any other cooling process, inasmuch as it cannot determine the descent of the cooled particles. The upper portions are cold by position; and if we suppose them to descend, as carried down, for example, by mechanical force, they would evolve their latent heat and assume the equivalent temperature of their new position as determined by the corresponding pressure.

Here we may make a few observations upon the question of the limits of such an atmosphere; a question, however, which does not materially affect the meteorological inquiries to which we are about to confine our attention.

Dr. Wollaston (*Phil. Trans.*, 1822,) attempted to estimate the probable height to which the earth's atmosphere extends, and has observed that from the law of its elasticity, which prevails within certain limits, we know the degrees of rarity corresponding to different elevations from the earth's surface; and if we admit that the air has been rarefied so as to sustain only $\frac{1}{100}$th of an inch of barometrical pressure, and that this measure has afforded a true estimate of its rarity, we should infer from the law that it extends to the height of forty miles with properties yet unimpaired by extreme rarefaction. Beyond this limit we are left to conjecture, founded on the supposed divisibility of matter; and if this be infinite so also must be the extent of our atmosphere. But if air consist of ultimate particles no longer divisible, then must expansion of the medium composed of them cease at that distance where the force of gravity downwards

upon a single particle is equal to the resistance arising from the repulsive force of the medium.

It has been very justly remarked, that a portion of air rarefied by means of the air-pump does indeed exhibit an elasticity which seems limited only by the imperfection of the instrument, for the most minute residuum still appears to fill the vessel and to press against it in all directions. But this is done at a temperature which, compared with that of the extreme boundaries of the atmosphere, is probably that of high-pressure steam to the water in a well. We know that in ascending into the atmosphere the temperature is found to decrease with the decreasing density of the air; and even between the tropics, beneath a vertical sun, there is a line of perpetual snow on the mountains, indicating a boundary within our reach, but which has never been penetrated by the subjacent mass of heated air. There is consequently no source from whence air conveyed to the summit of the atmosphere could obtain heat necessary to such extreme rarefaction; the sensible heat of the atmosphere being derived originally from the earth's surface. At an elevation, therefore, perhaps on a mean of not more than ten times that of the highest mountains, or of fifty miles at the equator, and considerably less at the poles, there must exist a perpetual and absolute zero of temperature, and with it an effectual limit to the further expansion of the atmosphere*.

* The question of a proper temperature of space it is not necessary to consider.

The self-congelation of carbonic acid which has been so recently effected adds greatly to the strength of this argument, and fair analogy authorizes us to conclude that the boundary of our atmosphere may consist of a stratum of frozen particles of nitrogen and oxygen perpetually falling into the warmer inferior strata to be again evaporated and again congealed in a process of continual circulation.

Astronomers have also sought to determine the elevation of the atmosphere by means of the duration of the twilight, and they have thence calculated it to extend to between forty and fifty miles above the surface of the earth.

Such, then, must be the constitution of an atmosphere of perfectly dry air, surrounding a sphere of the temperature of 32°: perfect equality of pressure producing perfect rest, the specific gravity, pressure and temperature decreasing upwards, according to the above scale, and each being definite for the elevation. These calculations have been made upon the supposition of equal gravity at all heights; a supposition, which is not exactly accordant with fact: the difference, however, is extremely small, and wholly unimportant to the general argument.

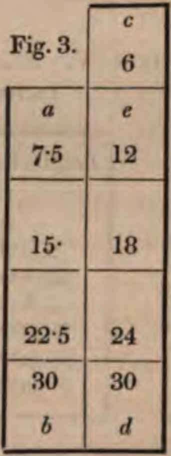
If the temperature of the sphere be now conceived to rise generally and equally in all its parts, a new adjustment of the gaseous strata must ensue. An increase of elasticity will take place, and the total height of the atmosphere will be increased. The expansion must necessarily proceed from below upwards; for the impulse, being equal and simultaneous in each

of the columns, into which we may suppose the atmosphere divided, they mutually confine one another in every other direction.

As there is no increase or decrease of ponderable matter in any of the vertical sections, the total pressure will remain as before, and a barometer at their bases will not be affected: but as a different distribution of the weight in the different horizontal sections takes place, the height of the barometer will vary with the altitude at which it is observed.

Putting the elastic force for the present out of consideration, let *a b* represent a column of fluid, whose total weight is 30, and whose four sections, taken at equal altitudes, are each 7·5: the scale of the progressive heights will be, 30, 22·5, 15·, 7·5. Let *c d* be the same column expanded by $\frac{1}{4}$ its length. Its total weight will be 30 as before; but the weights of its sections, taken at the same altitudes, will be reduced to 6, and the same progressive heights will be increased to 30, 24, 18, and 12. The quantity of matter remains the same, but a greater proportion of it is distributed in the upper parts. But if, in proportion as the expansion takes place, the fluid should overflow at its upper surface, so that the length of the column may remain the same, then would its total weight from *e* to *d* be reduced to 24, and that of its several progressive heights to 18, 12, and 6.

Fig. 3.



The first case presents us with an analogy adapted to our present purpose; the second we shall have occasion to apply as we proceed.

Upon the supposition which has been made, viz., of a general rise in the temperature of the sphere, the temperature of the atmosphere will be raised throughout its mass by internal circulation: the specific gravity as compared with the standard of 32° and 30 inches will be altered, but the proportion due to the several degrees of elevation will be ultimately preserved. The following Table exhibits the arrangement which would take place from an increase of 16 degrees of heat in the sphere:

TABLE IV. *Showing the effect upon the Barometer of a general Increase of Temperature in the Atmosphere.*

Height in Feet.	Barometer.	Sp. Gravity.	Temperature.
0	30·000	·96668	48
5,000	24·072	·80402	31·4
10,000	19·338	·66878	14·1
15,000	15·525	·55629	− 4·3
20,000	12·409	·46273	− 24·5
25,000	9·915	·38489	− 47
30,000	7·852	·32016	− 62·3

The height of the barometer at the base of the column, which denotes its total pressure, remains the same as in Table III., but increases at the various stages of altitude: the force of expansion having effected a different distribution of the ponderable matter, and raised a greater proportion to the upper regions. The density or specific gravity of the lowest

stratum of air, although the barometer is unchanged, is, however, diminished by the rise of the temperature.

Through this succession of changes, the atmosphere again attains a state of equilibrium and repose; and the action being equal all over the sphere, the adjustment is soon effected.

Let us next suppose that the temperature of the sphere, round which the atmosphere is diffused, instead of being equal in all its parts, increases by equal degrees from the poles to the equator; and let us assume that the temperature of the former is 0°, and the temperature of the latter 80°. The height of the barometer is still to be taken as 30·000 inches upon all parts of the surface. The following Table will exhibit the pressure, density, and temperature, at the two extreme points of such an arrangement, together with their gradual diminution for equal ascents:

TABLE V. *Showing the comparative Densities and Elasticities of two Columns of Air, of different Temperatures, at different Elevations.*

Height in Feet.	Barometric Column.		Specific Gravity.		Temperature.	
	Poles.	Equator.	Poles.	Equator.	Poles.	Equator
0	30·000	30·000	1·06666	·90000	0	80
5,000	23·597	24·342	·86935	·75737	– 18·5	64·4
10,000	18·587	19·779	·70856	·63735	– 37·8	48·4
15,000	14·591	16·060	·57752	·53640	– 58·8	31·4
20,000	11·411	13·043	·47071	·45150	– 82·1	12·8
25,000	8·900	10·521	·38365	·37980	– 109·1	– 7·6
30,000	6·906	8·483	·31270	·31980	– 140·3	– 30·7

In considering this arrangement, we may remark, first, that at the surface of the sphere, the pressure of

the air, as measured by the barometer, remaining the same, its specific gravity is very much greater at the poles than at the equator; and hence it is clear, that the atmospheric column must be proportionately shorter at the former, than at the latter point.

The further conclusion follows, that this heavier fluid must, by the laws of hydrostatics, press upon and displace the lighter; and a current will be established from the poles to the equator.

Our third remark is, that this difference of specific gravity becomes less as we ascend from the surface, and at a certain point is neutralized by the decrease of mechanical pressure; while, on the other hand, the elasticity, which is equal at the surface, varies with the height; and the barometer stands higher, at equal elevations, in the equatorial than in the polar column. This disproportion increases with the elevation; and at some definite height, must more than compensate the unequal density of the lower strata, and occasion a counter-current from the equator to the poles.

It will be convenient to consider these differences of gravity, and elasticity, as distinct and antagonist powers; and to measure their forces upon the same scale. This may readily be done, by considering, that the pressures of equal columns must be as their specific gravities, that is to say, in the previous example, ·90000 : 1·06666 :: 30·000 : 35·553, which gives an excess of 5·553 inches of mercury, as the measure of the excess of gravity in the case proposed.

We may illustrate this by the following hypo-

thetical case: suppose a column of air of standard density, confined in the closed leg of an inverted syphon by a small quantity of mercury; if mercury be poured into the other leg till it stand at 30 inches above the level of that in the first leg, the weight of the liquid will compress it to one-half its volume, and its elasticity will be doubled. If now the mercury be removed, the same compression may be produced by doubling the elasticity of the air in the second leg by means of a syringe.

This excess of gravity in the polar column, we have seen, is unopposed at the surface of the sphere by any excess of elasticity in the equatorial; so that it is the exact measure of the force with which the former would press upon the latter, supposing the two in juxta-position. It is also the measure of the pressure which would be required at the equator to equalize its density with that of the poles. If we could imagine this by any means effected, the barometer at the poles must rise to 35·55; and the current would be reversed, and flow with the same force from the equator to the poles; this current being now occasioned by excess of elasticity, as it was before caused by excess of gravity. An increased pressure of 2·77 inches at the equator would produce a state of perfect repose on the surface; the resulting augmentation of elasticity and gravity being jointly equal to the former excess of gravity. These forces being reciprocal in their action, any mechanical cause which acts upon the one, must equally affect the other. The following Table exhibits the excess of the two powers, together with their balance for the heights before assumed.

TABLE VI. *Showing the Force of the Polar and Equatorial Currents, at different Elevations.*

Height in Feet.	Elasticity.	Density.	Balance.	
0	−0·00	+5·55	+5·55	Lower Current from the Poles to the Equator.
5,000	−0·74	+3·73	+2·99	
10,000	−1·19	+2·38	+1·19	
15,000	−1·47	+1·37	−0·10	Upper Current from the Equator to the Poles.
20,000	−1·63	+0·64	−0·99	
25,000	−1·62	+0·12	−1·50	
30,000	−1·58	−0·20	−1·78	

The lower, or polar current, upon this supposition, extends to the height of about two miles and a half, gradually diminishing in force; and at that height, gives place to an upper or equatorial current, which increases in strength the higher we ascend.

The initial velocities of these currents may also easily be calculated: for as the velocity of air rushing into a vacuum*, is found by multiplying the square root of the height of the homogeneous atmosphere, expressed in feet, by 8, so will their rate be found, in the number of feet per second, by multiplying by 8 the square root of the height of a column of air equivalent to their respective forces. Thus the force of the polar current being 5·55 inches, the height of an equiponderant column of air would be 4856 feet, and $\sqrt{4856} \times 8$ would give in round numbers 557 feet per second, or 379¾ miles per hour. The rate of the equatorial current, at the height of 30,000 feet, by a similar calcula-

* YOUNG's *Natural Philosophy*, Vol. I., p. 279.

tion, would be about 312 feet per second ($\sqrt{1557 \times 8}$). These would be the initial velocities of the two currents; which, however, would be opposed and modified by the friction of the surfaces over which they flowed, and by the resistance and reaction of obstacles against which they might impinge.

But our hypothesis assumes, not that the equatorial and polar columns are in contact, but that the temperature graduates equally between the points; and, if we divide the hemisphere into bands of 10 degrees each, the pressure of the first upon the second will be equal to that of the second upon the third, and so on; that is to say, the greatest force of the lower current will be by our calculation 0·617 inches, and that of the upper 0·200 inches for every 10 degrees of latitude. Their respective velocities, equalizing them for each degree of heat, may also be approximated as follows. The extreme differences of 80 degrees we have seen are equivalent to 5·55 inches and 1·78 inches; and the intermediate differences of about 9 degrees to 0·617 inches, and 0·200 inches. The differences for each degree will therefore be ·068 inches and ·022 inches, which give a velocity of 61 feet per second for the lower current, and 32 feet for the higher, or about 41 and 20 miles per hour.

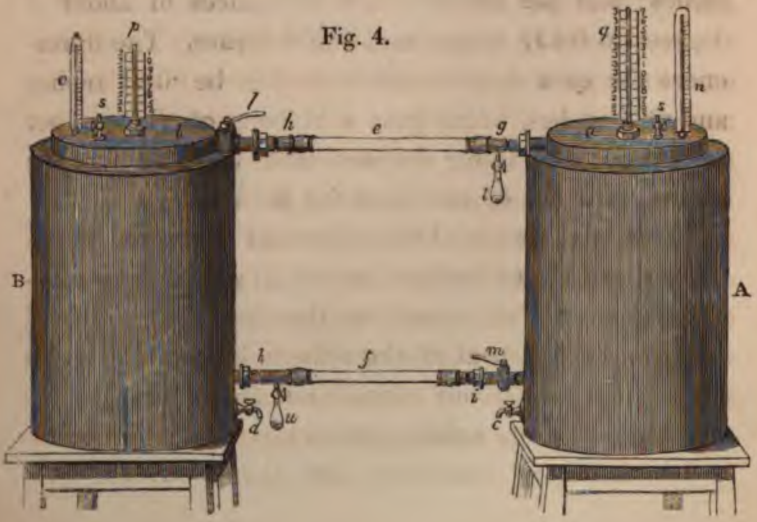
This interchange of the polar and equatorial atmospheres must tend towards an equalization of temperature, and, in fact, would in time produce an equal diffusion of the heat of the sphere itself, were not a cause included in our supposition to provide for the permanency of its existing state.

As we have calculated that these currents with

such respective degrees of force are the consequence of the equal height of the barometer all over the surface of our sphere, so we conclude that this equal height is maintained by this constant and regular flow; and any irregularity communicated to the currents would immediately be shown by a change in the mercurial column. Let us imagine for an instant that any cause (no matter at present whence originating) should retard the velocity of the polar current, without at first affecting the equatorial, which would flow on for a time with its acquired momentum: it is obvious that the barometer would fall at the equator and rise at the poles; for the balance of the forces would be disturbed by the want of compensation for the matter removed at one extremity and accumulated at the other.

The subject may derive some illustration from experiments with the apparatus, of which the following is a representation.

Fig. 4.



A and B are two large cylinders of zinc (31 inches in height and 20 inches in diameter), serving the purpose of cases, or jackets, to two air-holders of the same metal, *a* and *b*. *c* and *d* are two cocks by which any water between the air-holders and jackets may be discharged. *e* and *f* are glass tubes, of large diameter, passing through the exterior cases and connecting the two air-holders at top and at bottom by the connecting pieces, *g*, *h*, *i*, *k*. *l* and *m* are two large cocks, whose air-ways are equal in diameter to that of the glass tubes, and by which the communication between the air-holders may be cut off either at the top or bottom. *n* and *o* are two thermometers for denoting the temperatures of the air-holders, and *p* and *q* are two barometers, by which variations of the elasticity of the included air may be measured. *s* and *s* are stop-cocks, by which communication may be made or cut off between the air-holders and the exterior air. *t* and *u* are small glass flasks communicating with the tubes *e* and *f* by stop-cocks.

Previously to experimenting with this apparatus let a little solution of ammonia be thrown into the air-holders, and a little muriatic acid be poured into the flasks, carefully closing the stop-cocks of the latter.

1st. The barometers and the thermometers being at the same height in the two air-holders, let the connecting-cocks *l* and *m* be closed. If warm water be now poured into the space between the exterior cylinder, A, and its air-holder, its barometer, *g*, will rise, denoting an increase of elasticity exactly proportioned to the rise of its associated thermometer. Ice-cold

water poured into the apparatus, B, will occasion a similar fall in its barometer. The quantity of air in each remains as before.

2nd. If either of the lateral communications with the glass tubes be now opened, an equalization of pressure will immediately take place by a mechanical rush of air or wind from the more elastic atmosphere in A to B. If the communication be made by the lower cock, *m*, after the equalization of the barometers, a circulation will take place in B; the hot air injected at the bottom rising and slowly changing places with the cold air at the top till the temperature in B is equalized.

If instead of the lower cock, *m*, the upper cock, *l*, be opened, the equalization of the pressure will also take place; but after the mechanical disturbance of the air in B by the first rush of wind, the light warm air will lie upon the dense cold air without further disturbance.

3rd. Let both the cocks of the lateral communication be now opened and the barometers will remain at equal heights, denoting equality of pressure in the two air-holders; but a strong and very rapid current will be established from the heated atmosphere in A to the colder in B, along the upper tube, *e*, and a corresponding current of cold air from B to A, along the lower tube, *f*. The opposite courses of these currents may be rendered visible by opening the stopcocks of the small flasks, *t* and *u*, and by the application of a spirit-lamp injecting a small quantity of muriatic acid into the atmosphere, which by com-

bining with the ammonia with which it has been already impregnated will generate a dense cloud, by which the motions of the currents may be seen and measured.

This state of things now very accurately represents the phenomena of a hot equatorial column of the atmosphere in connection with a cold polar column of equal pressure at the surface of the earth. The current of cold air which rushes below into the hot atmosphere is exactly compensated by an equivalent flow of hot air above into the cold, and as long as this exact compensation takes place, the pressure in the two columns remains unchanged. But it is obvious that these strong self-compensating currents being once established, any causes which may act unequally upon them, to check or accelerate them unequally, must disturb their balance, and unequal pressures must arise.

4th. Thus, if we suddenly close one of the large cocks, *l*, after the establishment of the currents, the upper current will be stopped, but the lower current will be seen to flow on for a time by its acquired momentum, and thus air will pass by the lower passage from B to A, uncompensated by any return by the upper tube from A to B, and thus the pressure will become unequal in the two air-holders. It is true that in the experiments the momentum of the small quantity of air which constitutes the current, is not sufficient to act upon the large mass of mercury in the actual barometers, but the difference is clearly indicated by the motions of the clouds, which will be seen to spring back under the reaction of the accumulated force.

Such a separation of fluids into opposite currents, according to differences in their specific gravities, is sometimes observed in liquids. At the mouths of large rivers a stream of salt water may not unfrequently be seen running up the river underneath a descending stream of soft water. This phenomenon was recorded by Captain King, in the river Santa Cruz, during his voyage in the *Beagle*. (App. p. 297.)

Thus, then, our first *postulatum* constitutes an atmosphere which is necessarily at rest in all its parts: our second, occasions one as necessarily in regular and continual flux; let our third be a sphere increasing in heat, unequally, from the poles to the equator. The extremes are to be 0° and 80° as before, and at the middle point, or the latitude of 45°, we will suppose the temperature to be the exact mean of 40°: but from that centre, the increase towards the equator is to be by a rapidly and equally decreasing rate for equal distances, and the decrease towards the poles by a similar progression. The temperatures for every 10 degrees of latitude from the poles to the equator may then be as follows:

Pole	Lat. 80	Lat. 70	Lat. 60	Lat. 50	Lat. 45
0	3·2	9·6	19·2	32	40

Lat. 40	Lat. 30	Lat. 20	Lat. 10	Equator
48	60·8	70·4	76·8	80

The height of the barometer is still to be 30·000 inches everywhere upon the surface.

Table VII. furnishes us with the elasticity, specific gravity, and temperature of such an atmosphere, calculated upon these *data*, for every 10 degrees of lati-

TABLE VII. *Showing the Elasticity, Specific Gravity, and Te*
th

Height.	Poles.			Latitude 80.			Latitude 70.		
Feet.	Elast.	S. Grav.	Temp.	Elast.	S. Grav.	Temp.	Elast.	S. Grav.	Temp.
0	30·000	1·06666	0	30·000	1·06038	3·2	30·000	1·04685	9·6
5,000	23·597	·86935	−18·5	23·652	·86542	−15·2	23·707	·85684	− 8·5
10,000	18·587	·70856	−37·8	18·630	·70637	−34·3	18·724	·70140	−27·3
15,000	14·591	·57752	−58·8	14·642	·57654	−55·1	14·775	·57407	−47·7
20,000	11·411	·47071	−82·1	11·484	·47057	−78·2	11·617	·46991	−70·2
25,000	8·900	·38365	−109·1	8·965	·38408	−104·7	9·102	·38463	−96·3
30,000	6·906	·31270	−140·3	6·978	·31352	−135·7	7·100	·31483	−126·5

TABLE VIII. *Showing the Force of the Currents for di*

Height.	Latitudes 90 and 80.			Latitudes 80 and 70.			Latitudes 70 and 60.		
Feet.	Elast.	S. Grav.	Bal.	Elast.	S. Grav.	Bal.	Elast.	S. Grav.	Bal.
0	~	+·178	+·178	~	+·387	+·387	~	+·575	+·575
5,000	−·055	+·112	+·057	−·055	+·246	+·191	−·086	+·367	+·281
10,000	−·043	+·062	+·019	−·094	+·142	+·048	−·169	+·214	+·045
15,000	−·051	+·028	−·023	−·133	+·070	−·063	−·194	+·101	−·093
20,000	−·073	+·004	−·069	−·133	+·021	−·112	−·210	+·025	−·185
25,000	−·065	−·013	−·078	−·137	−·015	−·152	−·212	−·028	−·240
30,000	−·072	−·023	−·095	−·122	−·039	−·161	−·202	−·062	−·264

tude, from the surface, by equal altitudes, to the height of 30,000 feet. Table VIII. exhibits, in inches of mercury, the excess of the lateral pressure of each column upon that which adjoins, arising from the balance of forces.

It will be observed, that the currents still set as before, and at nearly the same altitudes, but with unequal velocities in different parts of their courses. The pressure, the density, the temperature, and the velocity, are all definite for the latitude, and for the elevation; and it is by the exact balance alone of these circumstances, that the barometer is maintained at an unvarying height, at the surface of the sphere.

Such abrupt inequalities of velocity, however, in the different parts of the same current, could not long exist, for a mechanical equalization would take place in the flow of the air from one latitude to another.

It must be remarked, also, that the motion of the air upon the surface of the sphere would be less and less obvious as its currents approached the equator, from the heating of the cold fluid and its tendency to rise, so that their course would be checked, till at length at the equator the opposite currents would meet and produce a calm. The line which divides the upper from the lower current divides the bulk of the whole atmosphere into two parts of equal weight, and the barometer which stands at 30 inches at the surface of the sphere, would stand almost exactly at 15 inches at their line of junction. The height of the polar current varies from 12,000 to 15,000 feet, not quite three miles; the height of the equatorial current which I

have not thought it necessary to include in my calculations beyond an equal distance, cannot be taken at less than ten times the amount.

We may now remark, that although a change of temperature, which equally pervades a column of air throughout its length, may effect an adjustment of density without disturbing the equiponderant mercurial column situated at its base: the force of the compensating currents will be altered; and under some circumstances, their courses even may be changed. Let us imagine that the temperature of latitude 50, as it stands in the preceding Table, is altered by some cause not affecting the neighbouring columns; and that the temperature rises from 32° to 60°·8 at its base, and equally pervades its whole length, so that the equivalents of temperature at the different heights are maintained: the force of the current will be increased from latitude 60 to 50, in its original direction, while that from 50 to 40 will be reversed, as will appear more clearly from the following Tables, in which the change is made according to this assumption.

TABLE IX. *Showing the Alteration of Specific Gravity and Elasticity in an Atmospheric Column, from an Increase of Temperature at the Surface of the Sphere in a given Latitude.*

	Latitude 60.			Latitude 50.			Latitude 40.		
Height.	Elast.	S. Grav.	Temp.	Elast.	S. Grav.	Temp.	Elast.	S. Grav.	Temp.
0	30·000	1·02707	10·2	30·000	·93960	60 8	30·000	·96668	48·
5,000	23·793	·84427	1·5	24·215	·78533	44·6	24·072	·80402	31·4
10,000	18·893	·69405	−16·9	19·531	·65639	27·9	19·338	·66878	14·1
15,000	14·969	·57061	−36·8	15·739	·54863	10·0	15·525	·55629	− 4·3
20,000	11·827	·46904	−58·8	12·673	·45856	− 9·4	12·409	·46273	−24·5
25,000	9·314	·38558	−83·8	10·162	·38327	−31·2	9·915	·38489	−47·
30,000	7·302	·31699	−112·7	8·135	·32035	−55·9	7·852	·32016	−62·3

TABLE X. *Showing, in inches of Mercury, the Alteration of Direction and Force in the Atmospheric Currents, from the same Cause.*

Height.	Latitudes 60 and 50.			Latitudes 40 and 50.		
	Elasticity.	Sp. Gravity.	Balance.	Elasticity.	Sp. Gravity.	Balance.
0	——	+2·560	+2·560	——	+0·840	+0·840
5,000	−0·422	+1·722	+1·300	−0·143	+0·580	+0·437
10,000	−0·638	+1·100	+0·462	−0·193	+0·380	+0·187
15,000	−0·770	+0·710	−0·060	−0·214	+0·240	+0·026
20,000	−0·846	+0·300	−0·546	−0·264	+0·130	−0·134
25,000	−0·848	+0·070	−0·778	−0·247	+0·050	−0·197
30,000	−0·833	−0·009	−0·842	−0·283	+0·006	−0·289

Here we perceive that the wind, which had blown on the surface from latitude 60 to 50, with a force of 0·810 inches, is now increased to 2·560 inches, and that which set from latitude 50 to 40, with a force of 1·034 inches, now blows from latitude 40 to 50, with a force of 0·840. A corresponding change of velocity and direction ensues in the upper currents, and the compensation of pressure thus takes place.

From the nature and essential properties of a permanently-elastic fluid, it follows that any cause tending to diminish gradually its specific gravity at the base of a column, or to augment it at its summit, must ultimately affect it throughout its length; so that, if its heat be slowly increased below, its temperature must rise from one extremity to the other.

But although such a change may take place, as has just been demonstrated, without affecting the length of the equiponderant column of mercury situated at the lower extremity, the barometer will rise

at all higher stations. By comparing together Tables VII. and IX., this effect will be easily appreciated. The augmentation of temperature in latitude 50 from 32° to 60°·8 takes place on the surface, while the mercurial column remains at 30 inches; but at the height of 5,000 feet it rises from 23·949 inches to 24·215 inches, making a difference of 0·266 inches. This difference increases to a certain extent with the elevation. Corresponding changes for less alterations of heat are readily perceived by comparing together the different latitudes of Table VII.

The cases which have hitherto been proposed have all been of the same nature: the alterations of temperature have been imagined to take place in the sphere itself, and from it to have been slowly communicated to the atmosphere, through which they have spread under the regular modifications due to the increasing capacities of its successive strata. Let us next consider the effect which would be produced by the heating of any of the upper layers, from some temporary cause, not originating in or extending to, the lower, but destroying the regular succession of equivalent temperatures. For this purpose, in the column appropriate to latitude 30, in Table VII., at the fifth station, or the height of 20,000 feet, we will suppose an increase of heat to take place of 10 degrees. This increase will extend upwards, but the inferior portions remain of their original temperature. Now, the first effect of this change will be, an augmentation of elasticity in the upper beds of the atmosphere; which, exerting its force upon the high

equatorial current, will accelerate its due velocity on one side, and retard it on the other. The expanding air, not being laterally confined by a proportionate expansion of the neighbouring sections, will not accumulate above; but will flow off, and its vertical pressure upon that column will cease. The upper regions will therefore be rarefied, and become lighter, and pressing with less weight upon the lower, the barometer will fall at the surface of the sphere in proportion to the amount of the expansion. This effect has been already explained in the second application of fig. 2.

Let us illustrate this action, by first representing the column, so partially changed in temperature, upon the supposition that no such compensation takes place.

Table XI. *Showing that a partial Alteration of Temperature and Specific Gravity in an Atmospheric Column must affect the Density generally by Mechanical Adjustment.*

Height.	Elasticity.	Sp. Gravity.	Temperature.	
			Regular.	Irregular.
0	30·000	·93960	60·8	60·8
5,000	24·215	·78533	44·6	44·6
10,000	19·531	·65639	27·9	27·9
15,000	15·739	*·53710	10·0	*20·
20,000	12·673	*·44890	− 9·4	* 0·6
25,000	10·162	*·37520	−31·2	−*21·2
30,000	8·135	*·31360	−55·9	−*45·9

The stations at which the changes of temperature take place, and the corresponding changes of specific gravity, are marked with asterisks.

That such a succession of densities would result is certain; for they are due to the given pressures

and temperatures: and it is also certain that such a succession could not exist in nature; for it is contrary to the fundamental law of geometrical progression. But if we suppose the barometer to fall, as represented in the following Table, the regular series is maintained. The stations at which the change of the mercurial column takes place are marked, as before, with asterisks.

TABLE XII. *Showing the Fall of the Barometer, which would be occasioned by a partial Alteration of Temperature in the upper part of an Atmospheric Column.*

Latitude 10.				
Height.	Elasticity.	Sp. Gravity.	Temperature.	
			Irregular.	Regular.
0	*29·37	·91990	60·8	60·8
5,000	*23·70	·76890	44·6	44·6
10,000	*19·12	·64270	27·9	27·9
15,000	15·73	·53710	*20	10·0
20,000	12·67	·44890	* 0·6	− 9·4
25,000	10·16	·37520	−*21·2	−31·2
30,000	8·13	·31360	−*45·9	−55·9

The density of an elastic fluid, as we have already pointed out, is the result of its gravity acting upon its elasticity, and by the reaction of these two powers any change in the vertical column is instantaneously communicated throughout its entire length, and no inequality of density can for a moment exist. Such a mechanical adjustment must, however, be unstable; and there will be a tendency to restore the natural equilibrium by processes of circulation which will be immediately set up.

Let us now imagine that the local accession of heat, instead of pervading at once the whole of either horizontal section, commences at some definite point, and gradually extends itself in depth. To render the march of this effect intelligible, we will consider its operation at several stages of its progress. We will first endeavour to appreciate the influence of an increase of 5 degrees of heat, at the height of 5,000 feet in the same column of latitude 30. The disturbing cause now affects the lower current, the expanding air of which, not being checked by a simultaneous increase of elasticity in the adjoining columns, rushes forwards with accelerated velocity on one side of the heated point, but is checked on the other. A diminution of density is occasioned by the excessive drain, and distributed throughout the column by mechanical adjustment. The results are as follow:

TABLE XIII. *Showing the Effect upon the Barometer of a partial Increase of Temperature at an elevation of 5,000 Feet.*

Latitude 30.				
Height.	Elasticity.	Sp. Gravity.	Temperature.	
			Irregular.	Regular.
0	*29·68	·92973	60·8	60·8
5,000	24·21	·77713	*49·6	44·6
10,000	*19·32	·64957	27·9	27·9
15,000	*15·57	·54829	10·0	10·0
20,000	*12·53	·45373	− 9·4	− 9·4
25,000	*10·05	·37921	−31·2	−31·2
30,000	* 8·05	·31690	−55·2	−55·2

The gradual extension of the same increase of heat to the height of 10,000 feet, produces the following arrangement:

TABLE XIV. *Showing the Effect upon the Barometer of an Extension of the Increase of Temperature to 10,000 Feet.*

Latitude 30.				
Height.	Elasticity.	Sp. Gravity.	Temperature.	
			Irregular.	Regular.
0	*29·37	·91990	60·8	60·8
5,000	*23·95	·76890	*49 6	44·6
10,000	19·32	·64270	*32·9	27·9
15,000	*15·41	·53710	10·	10·
20,000	*12·40	·44890	− 9·4	− 9·4
25,000	* 9·94	·37520	−31·2	31·2
30,000	* 7·96	·31360	−55·9	−55·9

Thus it appears that the fall of the barometer would be proportionate to the extent to which the rise of temperature would attain in this progressive manner. A small increase, operating in this manner, produces the same amount of depression, as if a greater expansion had been exerted in a more limited space. It is also important to remark that a rise in the barometer at the base of any column of the atmosphere, produced mechanically by an increased lateral pressure of adjacent columns, would cause an evolution of heat; whilst a fall arising from the opposite cause, would occasion a fall of temperature.

The following Table presents the effect upon the barometer of a gradual rise of two degrees of temperature, from 5,000 to 25,000 feet.

TABLE XV. *Showing the Effect upon the Barometer of a small partial Increase of Temperature, gradually extending itself throughout the Column.*

	Latitude 30. 1st Change.			Latitude 30. 2d Change.			Latitude 30. 3d Change.			Latitude 30. 4th Change.			Latitude 30. 5th Change.		
Height.	Elast.	S. Grav.	Temp.	Elast.	S. Grav.	Temp.	Elast.	S. Grav.	Temp.	Elast.	S. Grav.	Temp.	Elast.	S. Grav.	Temp.
0	*29·87	·9355	60·8	*29·74	·9314	60·8	*29·61	·9273	60·8	*29·49	·9232	60·8	*29·37	·9192	60·8
5,000	24·21	·7819	*46·6	*24·11	·7785	*46·6	*24·01	·7751	*46·6	*23·91	·7717	* 46·6	*23·81	·7683	* 46·6
10,000	*19·45	·6546	27·9	19·45	·6518	*29·9	*19·37	·6490	*29·9	*19·29	·6462	* 29·9	*19·21	·6434	* 29·9
15,000	*15·68	·5463	10·	*15·62	·5440	10·	15·62	·5417	*12·	*15·56	·5394	* 12·	*15·50	·5371	* 12·
20,000	*12·62	·4565	− 9·4	*12·57	·4545	− 9·4	*12·52	·4525	− 9·4	12·52	·4505	*− 7·4	*12·47	·4485	*− 7·4
25,000	*10·12	·3816	−31·2	*10·08	·3800	−31·2	*10·05	·3784	−31·2	*10·01	·3768	−31·2	10·01	·3752	*−29·2
30,000	* 8·10	·3190	−55·9	* 8·07	·3177	−55·9	* 8·04	·3164	−55·9	8·01	·3141	−55·9	* 7·98	·3138	−55·9

In the full effect of the three examples represented in Tables XII., XIV., and the last column of Table XV., the progression of density is the same; and the barometer falls to the same amount at the base of the column, notwithstanding the circumstances of the change of temperature by which it is occasioned are so different in each.

[illegible] of the action of the [illegible] column [illegible] and only by its amount and progress, but also by the [illegible] of the [illegible] [illegible] upon the lateral currents is calculated below.

TABLE XVI. Showing, in inches of Mercury, [illegible]

Height.	First Multiplication: Latitudes 40 & 30. Elast.	S. Grav.	Tot.	Latitudes [illegible]: Elast.	S. Grav.	Tot.	Second Multiplication: Latitudes [illegible]: Elast.	S. Grav.	Tot.	Latitudes [illegible]: Elast.	S. Grav.	Tot.	Third Multiplication: Latitudes [illegible]: Elast.	S. Grav.	Tot.	Latitudes [illegible]: Elast.	S. Grav.	Tot.
0	+·63	+1·44	+2·07	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]
5,000	+·37	+1·09	+1·46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10,000	+·21	+0·81	+1·02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15,000	−·21	+0·60	+0·39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20,000	−·26	+0·43	+0·17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25,000	−·25	+0·30	+0·05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30,000	−·28	+0·21	−0·07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

From latitude 40 to 30, it will be observed, that the force of the polar current is greatly increased; while from 30 to 20 it is reversed. The different modifications of the heating process produce different adaptations of the upper currents, which the comparison of the several tables will sufficiently explain.

It may readily be imagined, that irregularities thus introduced into these compensating movements, the consequence of diminished mechanical pressure, must of themselves be liable to produce changes of temperature in the columns, foreign to the natural gradation; and that amongst others, the atmosphere in its upper parts may be liable to greater depression of heat than would be due to the elevation alone. A gradual process of cooling taking place in the higher portions of a body of air, would communicate itself to the whole mass, in an analogous manner to the equal distribution which would ensue from the slow communication of heat to the lower parts; that is to say, without producing any effect upon the barometer, at the surface of the sphere, or any irregularity in the gradation in temperature. But where the change is effected suddenly, by the admixture of a large body of cold air, the regular series of equivalent temperatures is disturbed, a mechanical effect is produced by the increased pressure of the mass, and the equilibrium of density takes place before the proper adjustment of temperature. An atmosphere hence results, whose heat decreases in a proportion greater than is due to the decrease of density. The effect is analogous to that which arises from an irregular increase; and the barometer must rise, that is to say, the total pressure

Such a mechanical adjustment would, however, only produce a state of unstable equilibrium, the subversion of which might take place by the breaking down of the colder stratum in a current more or less perpendicular, instead of the compensation by lateral horizontal currents.

It is not required here to point out all the means by which such changes of heat as we have represented may be effected, or to trace further the endless modifications of densities and currents which would result from their different applications: it is sufficient, at present, to have shown that, supposing them to arise, certain general consequences must follow. Neither in the preceding Tables must absolute accuracy be expected; the mode of calculation which I have adopted did not admit of precision without a degree of labour which would have been disproportionate to the object which I have in view. Their use is to assist the mind in following the train of reasoning in the same way that rudely-sketched diagrams, out of all geometrical proportions, assist the mathematician in solving the problems of Euclid. The principle upon which they were constructed was to assume the mean temperature of the latitude for which it was wished to calculate the atmospheric column as the temperature of an homogeneous atmosphere, and thence to derive the pressure at different altitudes from the surface, and from them again the regular decrease of temperature for the density. It is clear that for accurate purposes, both the temperatures and pressures so obtained require correction. But the additional trouble of apply-

ing such corrections would have been very great; and the Tables, which even in their present state cost much pains, would not have better answered the purposes of illustration.

We have hitherto contemplated these changes with reference to the particular column of the atmosphere in which they had their origin; we must now endeavour to trace their effects upon those with which they are connected. We must recollect that it has been established as a principle, that the equal height of the barometer in every situation upon the surface of the sphere is dependent upon the maintenance of the equatorial and polar currents with a certain determinate velocity in the different parts of their courses, and that no disproportionate alteration or interruption in these can take place without a corresponding effect upon the mercurial column. Now, upon a reference to Tables VII. and VIII., it will be found that, to keep the barometer at 30·000 inches under latitude 40, a current is required of the force of 0·854 inches of mercury towards latitude 30, counterbalanced by one in the contrary direction of the force of 0·291 inches at the elevation of 30,000 feet; but by the unequal alteration of temperature shown in Table XIV., the current at the surface is increased to 2·07 inches, and continues with diminishing force to the height of 30,000 feet in the same direction. It is clear, therefore, that a much greater drain takes place upon this latitude without an adequate compensating supply; the barometer must, therefore, fall throughout the column. This fall, it will be observed, may take place without

any disturbance of the temperature. The atmosphere incumbent upon latitude 20, will be similarly affected by the same change of temperature at latitude 30. In its original state, the lower polar current flows upon the surface with a force of 0·648 inches, and feeds this column with a supply of air. It is balanced at the height of 30,000 feet by an equatorial current of 0·170 inches. The course of the former is now reversed, and the drain is increased in the contrary direction. A rapid fall of the barometer must, therefore, ensue.

On the other hand, an increased afflux of air beyond the usual supply to any portion of the atmosphere, occasioned by the expansion of any of the neighbouring parts, must cause an increase of pressure, and the equiponderant column will of course be lengthened. It is easy to perceive that these secondary effects must widely extend the influence of the original disturbing cause; and it is obvious that every depression of the barometer must be accompanied by an equivalent rise in distant parts of the elastic medium, and *vice versâ*. The local impulse extends its influence in this as in all other fluids, by the law of undulation. The mean pressure, at any moment of time, of all the waves upon the surface of the sphere, will be the pressure of the atmosphere at rest, and the average of a large number of oscillations at any particular spot will approximate to the same quantity.

It is obvious, likewise, that as the great antagonist currents upon which the atmospheric compensation

depends flow from the poles towards the equator, any disarrangement of their just balance will extend itself most in the direction of the meridians on which they occur, and will be marked by simultaneous changes of pressure either in excess or deficiency.

I have thus attempted to show that the proximate cause of the fall of the barometer at the surface of the sphere in an atmosphere constituted as our postulates have required, may be an increase of temperature in its upper parts beyond what is due to their respective elevations; and of its rise, an analogous decrease in the same situations. These changes I have endeavoured to exhibit as affecting directly the columns themselves in which the temperature varies, and remotely the adjoining columns, from their influence upon the lateral currents. This influence we have hitherto contemplated as extending only in the direction from the poles to the equator or from the equator to the poles, as if the changes of temperature which we have supposed had extended under the same parallel of latitude round the sphere. The course of our argument now requires that we should shortly consider the same changes as bounded in their longitudinal as well as in their latitudinal extent. For this purpose we must suppose our sphere to be divided into sections of 10 degrees at right angles to the former division.

Now, the arrangement represented in Tables VII. and VIII., resulted from the temperature of the sphere itself, which we supposed to increase in heat in a regular progression from the poles to the equator;

and the set of the aërial currents, under such circumstances, must necessarily be from north to south, and from south to north. But let us imagine that the local increase of heat, which is represented in Tables IX. X., is not only confined to 10 degrees of latitude, but also to 10 degrees of longitude: it will then be obvious that currents will tend to establish themselves at right angles to the former winds; and they will in some measure compensate the irregularity which has been introduced. The following Tables present the results of the calculation of these eastern and western currents.

TABLE XIX. *Showing the effects upon the Atmospheric Columns of a general alteration of Temperature in the direction of the Longitude.*

Height in feet.	Longitude 20 and 360.			Longitude 10.		
	Elasticity.	Sp. Gravity.	Temp.	Elasticity.	Sp. Gravity.	Temp.
0	30·000	1·00000	32·	30·000	·93960	60·8
5,000	23·949	·82656	14·8	24·215	·78533	44·6
10,000	19·106	·68321	−3·1	19·531	·65639	27·9
15,000	15·229	·56472	−22·4	15·739	·54863	10·
20,000	12·044	·46677	−43·6	12·673	·45856	−9 4
25,000	9·579	·38582	−67·5	10·162	38327	−31·2
30,000	7·566	·31890	−95·1	8·135	·32035	−55·9

TABLE XX. *Showing the Force, in inches of Mercury, of the Currents occasioned by the preceding Alterations.*

Height in feet.	Longitudes 360, or 20 and 10.		
	Elasticity.	Sp. Gravity.	Balance.
0	0	+1·929	+1·929
5,000	-·266	+1·301	+1·035
10,000	-·425	+0·837	+0·412
15,000	-·510	+0·496	-0·014
20,000	-·629	+0·251	-0·378
25,000	-·583	+0·076	-0·507
30,000	-·569	+0·043	-0·612

But that portion of the atmosphere which thus rushes to supply the place of the air which has been rarefied within the prescribed limits, is already, as we have seen, in motion from the pole to the equator: its course will, therefore, be intermediate between the two forces which impel it, and it will reach its destination with a northern or southern deflection. It will not be necessary to enter into the calculation of other cases of disturbance with the same limitations of longitude, as it is obvious that analogous effects must follow; and easterly or westerly currents, differently modified in direction and force, must result, whenever partial alterations of density take place, either from the immediate effects of expansion, or from change of mechanical pressure. The examples which have been adduced will be sufficient to illustrate the nature and operation of certain general principles, whose application is almost infinite.

There is, however, one more view of the subject

which may assist us in our after-application of these particulars to the intricacies of atmospheric changes. Referring back again to Tables VII. and VIII., let us now suppose an increase of ten degrees of temperature to take place along the whole extent of any given meridian, and a decrease of equal amount on the opposite line; and let all the meridians on each side be similarly affected in a regular gradation between the two. The distribution of heat upon these two lines, and the two intermediate, would be as follows, for every ten degrees of latitude.

TABLE XXI. *Showing the distribution of Heat all over the Sphere, upon the supposition of a gradual increase of Heat between the opposite Meridians.*

	Longitude 270	Longitude 0	Longitude 90	Longitude 180
Lat. 90	0	10·	0	−10·
Lat. 80	3·2	13·2	3·2	− 6·8
Lat. 70	9·6	19·6	9·6	− 0·4
Lat. 60	19·2	29·2	19·2	+ 9·2
Lat. 50	32·	42·	32·	22·
Lat. 40	48·	58·	48·	38·
Lat. 30	60·8	70·8	60·8	50·8
Lat. 20	70·4	80·4	70·4	60·4
Lat. 10	76·8	86·8	76·8	66·8
Lat. 0	80·	90·	80·	70·

This increase of heat, we are again to imagine to take place throughout the respective columns, in so gradual a manner as not to affect the barometer at their bases.

Then will two currents tend to form upon the sur-

face of the sphere, in opposite directions on either side of the cold meridian towards the hotter; or rather, the body of the air, which was before in motion from north to south, will now be deflected to the east and west; and the whole lower atmosphere, excepting upon these lines where the effect would be null, will move from the poles to the equator with a greater or less bend to the east and west. If the cause producing this variation of heat be supposed to move round the sphere from east to west, then will every meridian in succession be subjected not only to the inflowing of air alternately from the east and west, but to successive and alternate checks and accelerations of its own regular current. The effect would also be uniform from the pole to the equator.

Let us now suppose the surface of the sphere, instead of being level as we have hitherto imagined it, to be irregularly studded with inequalities of different altitudes, some of which reach into the upper current; in such case not only will great retardations and inequalities result in the motion of the lower current, but also deflections and eddies of considerable force, which must by a secondary influence affect the upper current, and cause variations in the total pressure of the perpendicular column.

All our reasoning has hitherto been applied to a sphere at perfect rest in itself: we will now suppose it to turn upon its axis with a certain regular velocity from west to east. We will, however, continue the supposition of equal gravity, and put out of consideration. for the present, the effect of centrifugal

force. The velocity of rotation of the single points of its surface will be in proportion to the semidiameter of the parallel circles under which they lie; such velocity, therefore, increases from the poles where it is zero, to the equator where it is greatest. The air which rests upon any point of its surface, if undisturbed by currents, will partake of the velocity of rotation due to such point: but in the cases which we have supposed of currents travelling from the poles towards the equator, the air not having attained the maximum velocity eastward of the latitudes at which it arrives, will have a relative motion westwards; and hence, the combined motion of the wind will be directed in the northern hemisphere from north-east to south-west; and in the southern, from south-east to north-west. The deviation from its original direction will be the greater, the more the velocity of rotation of the point of starting differs from the velocity of rotation of the places at which it arrives.

Whenever this apparent tendency coincides with an actual impulse in the same direction, derived from other sources, it will augment its force; and when opposed to one in a contrary direction, it will tend to neutralize it. Thus, in the supposition which has been made above, of an accession of temperature upon the whole of any one meridian, the current, which we found would thence arise from the east towards that meridian, would be increased by this further mechanical impulse; while the western current on the opposite side would be decreased, if not annihilated. And here we may remark that the lower currents

[illegible], which we have supposed to flow in contact with the sphere even when at rest, will be considerably checked by the friction of its surface.

But as the lower polar current would thus have a relative western direction, with regard to the motion of the sphere itself, so the upper equatorial current would have an *absolute* movement communicated to it in the contrary direction. The particles of air, which are transported from the polar regions to the equator, have not time to assume the velocity of the different parallels of latitude as they reach them; and are, therefore, necessarily behind them, as they revolve. To other bodies, therefore, possessing that velocity, they oppose a resistance which appears to come from the eastern quarter. Those, however, which are transported above from the equator to the poles, have an excess of absolute motion from west to east above those parts of the globe towards which they are carried. This motion, originally transferred by the upper current, will ultimately affect the lower by the necessary interchange of particles between the two, dependent upon the heating and cooling processes. As the heating power, which is the main-spring of all the motions of the atmosphere, is supposed to be in the sphere itself, it follows that the upper or most remote parts of the atmosphere will become cooled by radiation beyond the equivalent of their position; while those which are nearer to, or in contact with it, maintain their proper temperature. As they cool, they of course become specifically heavier and descend, their place being supplied from the subjacent warmer strata.

Another kind of circulation is thus established in a direction perpendicular to the horizontal currents which we have been considering, and not necessarily interfering with them. The interchange of heated particles from below, and of cooled particles from above, may be conceived to be effected in so regular a manner, as that they may exactly compensate each other; and thus the normal equivalents of temperature are maintained at their proper respective altitudes. If we consider, therefore, the motion of any one particle of air, we shall find that its course has an angular direction compounded of these two motions.

Fig. 5.

Let A B, fig. 5, represent an upper, and C D an under current of air, moving with equal velocities in opposite directions. Let us take any particle in the higher E, and suppose it to have a density greater than is due to its situation, then will its course be from E to F, in an inclined direction, resulting from the two forces which solicit it. If we follow it further, we shall find that one of these forces ceases its action, and gives place to another in a contrary direction; its path will then be from F to G, resulting from the other force, which continues its action, and the new impulse which it now receives. In this manner may an interchange of particles be kept up between the two principal

currents, without at all interfering with their courses. We have, however, just observed, that the upper equatorial current is endued with an additional movement from west to east greater than that of the polar latitudes towards which it is carried: this impulse, being unopposed, must be borne by the particles in their descent from the higher to the lower stream; and the consequence must be, that the latter will be deflected from its course; and the northern current will receive a westerly direction at the point where this influence reaches its stream with sufficient power.

Such a deflection would necessarily ensue from the gradual interchange of the heated and cooled particles of the two currents animated by the secondary forces. But if the upper current, by a concentration of its force, or by more rapid cooling, were conceived to descend bodily, so as to break in upon the course of the lower current, then would a conflict of the two take place, in which one would sometimes displace the other. Sometimes the polar current would be borne back or lifted from the surface by the momentum of the equatorial: at other times the reaction would cause the former to return with increased energy; or perhaps more frequently would compensate the displacement in one region by a corresponding increase of velocity in another. Now, if we imagine our sphere to turn upon its axis with the same velocity as the earth, the space between the equator and latitude 30° will revolve with an average easterly motion of about 950 miles per hour; while the space between latitudes 30° and 40° would not revolve with a greater velocity

than 800 miles. It is obvious that the polar current, as it flows along the surface, expands as the meridians open out, and from friction against the solid obtacles which it encounters, speedily adapts itself to the rate of the different parallels at which it arrives. The particles of the upper equatorial current, on the contrary, in their motion to the poles, lose nothing of their momentum which they have acquired by rotation, but moving upon converging lines, descend when cooled with full force upon the higher latitudes. The westerly direction would thus be communicated with increased energy to the atmosphere, at the points where this influence first met with the surface of the sphere; but conflicting forces and opposing obstacles would prevent the establishment of that exact regularity which prevails in the intertropical regions, where the movements originate. The balance of all the movements below must, however, return as much air to the equator as is abstracted by the more equal current above.

The point at which the upper current communicates its influence to the lower will be more or less remote from the equator, in proportion to the rate at which the current travels, and the energy of the circulation; but from the nature of the process, it is obvious that it must at all times lie at a considerable distance from it.

In the case of such reversals of the regular currents as we have contemplated, from local changes of temperature and changes of barometric pressure upon the surface, it is clear that whenever the atmosphere flows

from a lower parallel of latitude and reaches a higher, it must carry the same tendency from the west with it, and the more westerly will it become the further apart from each other the parallels may be.

We must not, moreover, quite lose sight of the influence of the centrifugal force at the equator; for upon the supposition of a velocity of rotation equal to that of the earth, it would amount to $\frac{1}{289}$th of the force of gravity; and on this account the barometer would stand 0·104 inches lower at the equator than at the poles, provided no compensation took place.

We have thus, by gradual stages, obtained some insight into the properties of an atmosphere of permanently-elastic fluid, surrounding and gravitating towards a sphere of unequal temperature, increasing from the poles to the equator, and revolving upon its axis with equal and definite velocity. The state of equilibrium, which it must always be striving to attain, by whatever obstacles opposed, is maintained by two grand systems of currents, equally balanced, varying in force and direction, and originating partly from differences of density and elasticity, and partly from relations to the rotatory movement. The principal circulations are in a horizontal direction from the poles to the equator, in the lower system: and from the equator to the poles in the upper: and in a vertical direction, a constant interchange of particles between the superior and inferior strata. These motions are effected by means of differences of temperature and consequent differences of density. Subordinate to this influence of heat is that of the momentum of the air

in different degrees of rapid rotatory movement, which produces certain deflections from the primary directions of the currents; but, as the upper and lower systems are oppositely affected throughout, they compensate each other's motions, and their combined pressure is the same in every part. In this nicely-balanced order of things, we have seen how slight irregularities of temperature might produce great disturbances, and we have traced various expansions and contractions, which acting unequally upon the antagonist currents, would destroy the adjustment of their several velocities. Accumulations in some parts, and corresponding deficiencies in others, would hence arise, the amount of which would be weighed by the barometer. These, in seeking to regain their proper level, and struggling to restore the equilibrium, would give rise to temporary and variable winds, which would modify the regular currents, and often reverse their courses.

The currents of a heated room in some measure exemplify these great currents of our atmosphere. If the door be opened, the flame of a candle held to the upper part will show by its inclination a current flowing outwards; but if held near the bottom, it will be directed inwards. If a door opening *outwards* be suddenly closed, it moves with the incoming current and against the outgoing, and a condensation of air takes place in the room, which is evidenced by the the rattling of the windows and the bursting open of any other door in the room which may happen to be slightly closed, and to open *outwards*. If a door opening *inwards* be suddenly closed, it moves against

the incoming current and with the outgoing, and a rarefaction of the air in the room takes place, which is shown by the rattling of the windows and the bursting open of any other slightly-closed door in the room which may open *inwards*.

The system of self-compensating currents is applied with the greatest advantage to the ventilation of mines; and the means which are there employed for the renewal of the air offer us another appropriate illustration of the subject. In an adit in which a stream flows there is placed at a small elevation above the latter a partition of boards; below this partition the air follows the course of the stream; above, it takes the contrary direction.

Having established these several particulars, as it is believed, upon fixed and acknowledged principles, let us now proceed to investigate the third division of our proposed inquiry.

PART III.

ON THE HABITUDES OF AN ATMOSPHERE OF PURE AQUEOUS VAPOUR.

In the second part of this Essay we have considered the habitudes of an atmosphere of perfectly dry and permanently-elastic fluid: the third branch of the investigation leads us to the consideration of an atmosphere of pure, unmixed, aqueous vapour. Let us first contemplate it, in this as in the former case, as surrounding a sphere of uniform temperature, which we must now suppose to be covered with water. This temperature we will fix at 32°, as in our first hypothesis of the permanently-elastic fluid. It will not be necessary here to make any distinction between water in its fluid, and in its solid, state: for it has been well ascertained that ice, as well as water, yields vapour of elasticity proportionate to its temperature; the general term water may, therefore, be employed without impropriety, and we will imagine our liquid stratum just above its point of congelation.

Now the elastic force of steam, for the different degrees of heat within the range of atmospheric temperature, has been determined with very great precision by different philosophers. The following table, extracted from the works of Dr. Dalton, includes the results as far as they are necessary to our present purpose:—

TABLE XXII. *Showing, in inches of Mercury, the elastic Force of Vapour for every Degree from 0° to 90°.*

Temp.	Pressure.	Temp.	Pressure.	Temp.	Pressure.	Temp.	Pressure.
0	0·064	22	0·139	45	0·316	68	0·676
1	·066	23	·144	46	·328	69	·698
2	·068	24	·150	47	·339	70	·721
3	·071	25	·156	48	·351	71	·745
4	·074	26	·162	49	·363	72	·770
5	·076	27	·168	50	·375	73	·796
6	·079	28	·174	51	·388	74	·823
7	·082	29	·180	52	·401	75	·851
8	·085	30	·186	53	·415	76	·880
9	·087	31	·193	54	·429	77	·910
10	·090	32	·200	55	·443	78	·940
11	·093	33	·207	56	·458	79	·971
12	·096	34	·214	57	·474	80	1·000
13	·100	35	·221	58	·490	81	1·040
14	·104	36	·229	59	·507	82	1·070
15	·108	37	·237	60	·524	83	1·100
16	·112	38	·245	61	·542	84	1·140
17	·116	39	·254	62	·560	85	1·170
18	·120	40	·263	63	·578	86	1·210
19	·124	41	·273	64	·597	87	1·240
20	·129	42	·283	65	·616	88	1·280
21	·134	43	·294	66	·635	89	1·329
		44	·305	67	·655	90	1·360

The tension of vapour at different degrees of atmospheric temperature is easily measured by throwing a little water up into the vacuum of a well-boiled barometer. The column of mercury will be depressed by the amount of the elasticity due to the temperature of the vapour, and this depression may be readily ascertained by comparison with a dry barometer.

According to the preceding table, with the temperature at 32°, the equiponderant column of mercury

would be ·200 inch; and it would be the same at every part of the surface. The density of the vapour, like that of the gaseous atmosphere, and for the same reasons, must decrease in a geometrical progression for equal perpendicular distances, and the temperature will decline with it. The ratio, however, of its diminution will be very different.

To exemplify the calculation, we will take the height of 10,000 feet. We must first find the height of an homogeneous atmosphere of such vapour equivalent to ·200 inch of mercury. Its specific gravity, compared to dry air, is as 2·317 to 557·800, or as the weights of a cubic foot of each respectively; therefore, 2·317 : 557·800 :: 10500 : 2527794, then 2527794 × 0·2 inch = 505558 inches = 42129 feet,

$$\text{and } \underset{\text{Height of Homogeneous Vap.}}{42129} : \underset{\text{Given height}}{10000} :: \underset{\text{Modulus of Logarithm.}}{\cdot 4342945} : \underset{\text{Diff. of Log. of Densities.}}{\cdot 1030868}$$

$$\begin{aligned} \text{Log. of } \underset{\text{Density, at } 32^\circ.}{\cdot 200} &= \cdot 3010300 \\ &- \cdot 1030868 \\ &= \cdot 1979432 = \text{Log. of } \underset{\text{Density, at } 25^\circ.}{\cdot 157} \end{aligned}$$

At the height, therefore, of 10,000 feet, the mercurial column, which the atmosphere would support, would only be ·157 inch, and the constituent temperature of vapour of this degree of elasticity is 25°, as is shown in the preceding Table. In this manner the following Table was constructed of the elasticity, density, and temperature of such an atmosphere as we are now contemplating, at different heights; and we of course imagine it not to be exposed to any

cooling influence from without, or from its own radiation.

TABLE XXIII. *Showing the Decrease of Density and Temperature in an Atmosphere of Aqueous Vapour, of the force of ·200 inch at different Elevations.*

Height in Feet.	Elasticity.	Density.	Temp.
0	0·200	1·000	32
5,000	·177	·890	28·5
10,000	·157	·790	25
15,000	·140	·708	22
20,000	·124	·636	19
25,000	·110	·577	16
30,000	·100	·518	13

With such an arrangement, there would be perfect equilibrium, and consequently perfect rest, all over the sphere. No precipitation or evaporation would take place, and the atmosphere would remain transparent and undisturbed. Such also must be the state to which an atmosphere of vapour would strive to attain, notwithstanding any obstacles which might be opposed to it. Hence we may also infer that, if condensation were to take place in any part of such an atmosphere, evaporation must follow in other parts to maintain the balance of forces; and conversely, that evaporation must be accompanied by precipitation.

Should the temperature of the sphere rise gradually and equally over all its surface, the elasticity of the steam would increase with it, without disturbance; and, following its own law of decrease for different elevations, would remain perfectly transparent and

quiescent. The total amount of the atmosphere might be estimated, like that of the gaseous atmosphere, by the column of mercury which it would support at the surface of the sphere; or by the constituent temperature, the relation of which to its elasticity has been determined, in the manner already pointed out.

In considering the second modification of circumstances, that, namely, of the temperature of the sphere increasing from the poles to the equator, we must first observe, that a pure unmixed atmosphere of vapour could not follow such a gradation. The ultimate elasticity of the whole would be determined by that of the lowest point; and the water would distil from the hottest point to the coldest, with such rapidity, as to occasion strong ebullition at the former. This may be exemplified by the apparatus of the barometer containing a portion of water, to which we have just referred. The tension of the vapour increases with the temperature, provided the whole space through which it is diffused be heated to an equal degree; but by heating the water alone by the warmth of the hand or otherwise, it may be made to boil, without increasing the elasticity of the vapour; which is condensed in the upper part of the tube as soon as it is formed in the lower.

The condensation of vapour may be effected, not only by decrease of temperature, but by increase of pressure: it is not necessary, therefore, that it should pass from the hottest to the coldest point to be precipitated, which would be a gradual process; but the elastic force, arising from an increase of density at one

cooling influence from without, or from its own radiation.

TABLE XXIII. *Showing the Decrease of Density and Temperature in an Atmosphere of Aqueous Vapour, of the force of* ·200 *inch at different Elevations.*

Height in Feet.	Elasticity.	Density.	Temp.
0	0·200	1·000	32
5,000	·177	·890	28·5
10,000	·157	·790	25
15,000	·140	·708	22
20,000	·124	·636	19
25,000	·110	·577	16
30,000	·100	·518	13

With such an arrangement, there would be perfect equilibrium, and consequently perfect rest, all over the sphere. No precipitation or evaporation would take place, and the atmosphere would remain transparent and undisturbed. Such also must be the state to which an atmosphere of vapour would strive to attain, notwithstanding any obstacles which might be opposed to it. Hence we may also infer that, if condensation were to take place in any part of such an atmosphere, evaporation must follow in other parts to maintain the balance of forces; and conversely, that evaporation must be accompanied by precipitation.

Should the temperature of the sphere rise gradually and equally over all its surface, the elasticity of the steam would increase with it, without disturbance; and, following its own law of decrease for different elevations, would remain perfectly transparent and

quiescent. The total amount of the atmosphere might be estimated, like that of the gaseous atmosphere, by the column of mercury which it would support at the surface of the sphere; or by the constituent temperature, the relation of which to its elasticity has been determined, in the manner already pointed out.

In considering the second modification of circumstances, that, namely, of the temperature of the sphere increasing from the poles to the equator, we must first observe, that a pure unmixed atmosphere of vapour could not follow such a gradation. The ultimate elasticity of the whole would be determined by that of the lowest point; and the water would distil from the hottest point to the coldest, with such rapidity, as to occasion strong ebullition at the former. This may be exemplified by the apparatus of the barometer containing a portion of water, to which we have just referred. The tension of the vapour increases with the temperature, provided the whole space through which it is diffused be heated to an equal degree; but by heating the water alone by the warmth of the hand or otherwise, it may be made to boil, without increasing the elasticity of the vapour; which is condensed in the upper part of the tube as soon as it is formed in the lower.

The condensation of vapour may be effected, not only by decrease of temperature, but by increase of pressure: it is not necessary, therefore, that it should pass from the hottest to the coldest point to be precipitated, which would be a gradual process; but the elastic force, arising from an increase of density at one

The vapour will flow in a mass from the equator to the poles, and, being necessarily condensed in its course, will return from the poles to the equator in the form of water. Great evaporation will constantly be going on at the latter station, and condensation at every other: so that the atmosphere, excepting at the equator, would be rendered turbid by perpetual clouds and rain. As in the case of the permanently-elastic fluid, the temperature of the sphere would, by this process, soon become equalized, did not our hypothesis provide for its permanency: the equatorial parts would be quickly cooled by the evaporation, and the polar warmed by the heat evolved during the condensation.

It is further worthy of attention, that, the elasticity of vapour increasing nearly in a geometrical proportion for equal increments of heat, the decrease of temperature in ascending in this atmosphere will be in arithmetical proportion only. The diminution is very nearly three degrees for every 5,000 feet.

Upon the hypothesis of the gradation of temperature before assumed, in the case of the gaseous atmosphere, the following Table will represent the corresponding elasticity and density of the vapour, at the surface of the sphere, for every ten degrees of latitude; the density at 32° being, as before, taken as the standard of comparison.

TABLE XXV. *Showing the Force and Density of an Atmosphere of Aqueous Vapour, for every Ten Degrees of Latitude, surrounding a Sphere unequally heated.*

Poles.			Latitude 80.			Latitude 70.			Latitude 60.			Latitude 50.		
Elas.	Density.	Temp.	Elas.	Density.	Temp.	Elas.	Density.	Temp.	Elas.	Density.	Temp.	Elas.	Density.	Temp.
·064	0·340	0	·072	0·380	3·2	·089	0·466	9·6	·125	0·641	19·2	.200	1·000	32
Latitude 40.			**Latitude 30.**			**Latitude 20.**			**Latitude 10.**			**Equator.**		
Elas.	Density.	Temp.	Elas.	Density.	Temp.	Elas.	Density.	Temp.	Elas.	Density.	Temp.	Elas.	Density.	Temp.
·351	1·700	48	·539	2·547	60·8	·731	3·403	70·4	·900	4·143	76·8	1·000	4·571	80

Under these circumstances, the equatorial regions will remain perfectly transparent, while clouds will be formed and rain precipitated in every other situation, in consequence of the lateral flow of the vapour towards the poles, in proportion to the densities of the air at the respective places and the decrease of temperature; and the supply of vapour will be entirely kept up by the evaporation at the equator. This circulation may be regarded as a species of regulated distillation. The height of the barometer decreases rapidly towards the poles from 1 inch to ·064 inch, and the quantity of condensation is definite for each latitude; for the hypothetical mechanical resistance to the passage of the vapour is supposed to be constant and equal.

Let us now imagine that the temperature of the globe at any particular latitude is raised to the level of the lower adjoining latitude: then will condensation

cease at that particular latitude, evaporation will commence, and the atmosphere will become transparent. The quantity of water precipitated will be proportionally increased on the adjoining higher latitude. If, on the contrary, the temperature be lowered to the standard of the latitude next above, the precipitation will be increased, and the higher latitude will be cleared. The following Table represents latitude 30 under these two conditions.

TABLE XXVI. *Showing the State of the Atmospheres arising from Alterations of Temperature in any intermediate Columns.*

Latitude 40. Cloudy.			Latitude 30. Clear.			Latitude 20. Cloudy.		
Elas.	Density	Temp.	Elas.	Density.	Temp.	Elas.	Density	Temp.
·351	1·700	48	·731	3·403	70·4	·731	3·403	70·4
Clear.			Cloudy.			Cloudy.		
·351	1·700	48	·351	1·700	48	·731	3·403	70·4

Again, if the mechanical retardation of the flowing vapour, which we have imagined, were subject to variation, the quantity of evaporation and precipitation would be proportionate to the velocity of its passage; thus, supposing the evaporation from a given surface at a given temperature, and under a certain resistance, to be three grains per minute, it would be increased to six grains with half the resistance. It would be easy to apply these consequences to analogous cases, but it will not be required to trace them more parti-

cularly. The changes at the surface produced by this lateral action of the vapour, affect the whole of the superincumbent columns equally, and the temperature of the vapour in each follows its own law of decrease.

But what will be the consequence, if the vapour should be forced to adapt itself to a progression of temperature different from that of its own; as if, from some cause or other (no matter at present whence originating) the heat of the upper regions should diminish at a greater rate than is due to the natural gradation of such an atmosphere?

Let us, for instance, suppose that the heat of the water upon the sphere is 80°, but that, at the height of 5,000 feet above the surface, a temperature exists of 64°·4, which from that point follows the regular decreasing scale for an atmosphere of vapour. The water will have a tendency to throw off vapour of the same constituent heat as its own temperature; but the pressure above, being rendered too little by the influence of the forced degree of cold, to preserve the necessary elasticity below, the atmosphere will only possess the tension due to the lower degree; that is to say, the constituent temperature of the vapour will be only 67°·9, or that of vapour of the elastic force of 64°·4, added to the amount due to the height or pressure of the column. Evaporation must therefore ensue below, and its concomitant precipitation will take place above. The calculation of these effects has furnished the following tabular representation of their connection:

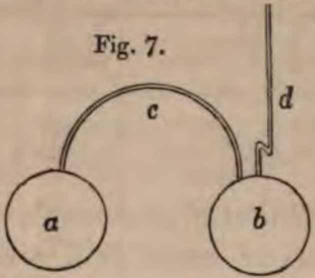
TABLE XXVII. *Showing the Effect upon the Atmosphere of Vapour of a forced gradation of Temperature.*

Height in Feet.	Elasticity.	Constituent Temp. of Vapour.	Sensible Temp.	State of Atmosphere.
0	*·673	*67·9	80	Clear
5,000	*·606	*64·4	*64·4	Cloudy
10,000	·542	61	61	Clear
15,000	·490	58	58	"
20,000	·443	55	55	"
25,000	·401	52	52	"
30,000	·363	49	49	"

The consequence of this situation of things will be, that a cloud will be formed at the height which has been named: for the atmosphere will be forced upwards by the spring of the nascent vapour below, and will be condensed at this point. The cloud, however, supposing the process to be sufficiently gradual, would not extend very far downwards, for the water, during its precipitation, would be re-evaporated by the excess of heat in the lower regions, so that they might remain transparent and undisturbed. The ultimate effect would be that the temperature would be slowly equalized, and the balance of force restored. The water, in its circulation backwards and forwards, would act as a carrier of the heat, which it would abstract from the lower parts by its evaporation, and give out to the upper by its condensation. The atmosphere would thus gradually recover its state of equilibrium and repose. The upper regions, upon this supposition, would remain clear, for there the regular gradation is undisturbed.

This part of the subject may, perhaps, derive some illustration from the following analogy and figures:

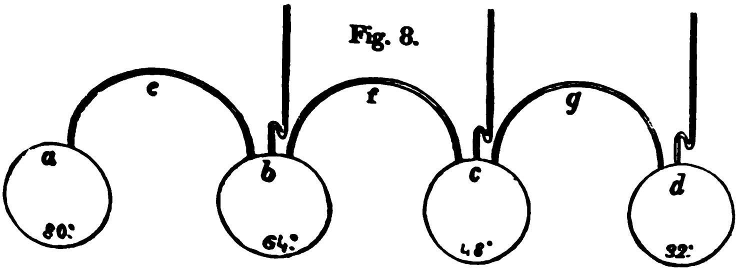
Fig. 7.



Let *a* and *b*, fig. 7, represent two glass globes connected together by the tube *c*:—*d* is a mercurial gauge for the purpose of measuring the elasticity of any included vapour. Let us suppose the apparatus to be free from air, and water to be included in *a*; and let the temperature of both the globes be 80°. The column of mercury supported in *d* will then be equal to 1 inch, and no evaporation or condensation can take place. Let us now imagine the globe *b* to be suddenly cooled down to 32°. The mercury in the barometer *d* will instantly fall to ·200 inch; the water will rapidly evaporate, and be condensed in *b*, and if both the temperatures be maintained, will entirely pass from *a* to *b*, as in the cryophorus. The difference, between the force of vapour at 80° and 32°, will thus become the measure of the force of evaporation.

Now let the following figure represent four globes, connected together in the same way as the two in fig. 5. The whole apparatus is supposed to be free from air, and the ball *a* to contain water. The temperature of each is to be maintained respectively at 80°, 64°, 48°, and 32°.

Fig. 8.



The gauges would then all denote a tension of ·200 inch, and the water would distil over rapidly into *d*. The vapour in its passage meets with no obstruction, and the effect is necessarily the same as in the last case, where no intermediate receivers were placed. But, should the vapour be retarded in its course by any obstacle of a mechanical nature, as if the connecting tubes, *e*, *f*, and *g*, were packed with sand or cotton, or were separated by diaphragms of plaster of Paris, or moist bladder, the result would be very different. At the commencement of the process the rising steam would assume the elasticity necessary to enable it to pass the intervening obstructions into the globe *d*, and whatever this elasticity might previously be, when the vapour reached *d*, it would be reduced to the force of ·200 inch. With this force it would, therefore, react upon the surface of the water in *a*. The nascent steam has now not only the mechanical impediment to overcome but this additional pressure, so that its elasticity, and consequently its temperature, must rise in proportion. In *c*, however, it necessarily assumes the temperature of that vessel. A greater degree of elasticity from *c* to *a* now presses upon the fluid, and the force of the generated steam must again rise.

It is again partly condensed in *b*, whose temperature will not support the higher degree, and the increased tension is exerted from *b* to *a*. The different gauges, *b c* and *d*, will thus denote the respective elasticities, ·597 inch, ·351 inch, and ·200 inch, appropriate to their several temperatures. The differences of force also will denote the rate of evaporation in each: for it has been shown that the column of mercury equivalent to the elasticity of the vapour at a given temperature expresses accurately enough the mean evaporation in 24 hours from a surface of water into a dry atmosphere; and the existence of any previous vapour is allowed for by deducting its elastic force from that due to that given temperature*.

Such mechanical obstruction, as we have supposed, would oppose itself to the free passage of vapour in motion, but would exert no pressure or influence upon it in a state of rest; and if we were to imagine that all the water had distilled over from *a*, and were included in *d*, the gauges would all stand permanently at ·200 inch.

Let us now apply this illustration to our atmosphere. We have already proposed the simple case of a sudden decrease of heat at one stage of its height, by which condensation was produced; the elasticity was thereby reduced to the degree appropriate to that temperature at that elevation, and evaporation commenced from the surface. This evaporation was proportionate to the difference between the elasticity of

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* See Essay upon Hygrometry.

vapour of the temperature of the sphere, and the elasticity of the superincumbent mass. We will now suppose that the rapid decrease of temperature continues throughout the column, and that at the following stages of its height it is forced to adapt itself to the annexed progression.

TABLE XXVIII.

Height in Feet.	Temperature.
0	80·
5,000	64·4
10,000	48·4
15,000	31·4
20,000	12·8
25,000	− 7·6
30,000	−30·7

The elasticity could not then exceed ·043 inch upon the surface: the evaporation would consequently be excessive, while the condensation above would be proportionate, and the precipitation would resemble a water-spout in its effects. We must now provide (and by what means we will not now stop to inquire) some obstacle by which the course of the vapour may be retarded in its ascent, in a similar way to that which we have imagined in the glass globes,—then may the condensation take place gradually and at different heights. The relative distances of these points of precipitation will depend upon the force of the vapour, and the greater or less facility with which it overcomes the mechanical obstruction. For the scale of temperature laid down, the following Table would represent

an adequate balance of evaporation and condensation, with the appropriate degrees of elasticity between the points.

TABLE XXIX. *Showing the Effects of a further forced Progression of Temperature upon the Atmosphere of Vapour.*

Height in Feet.	Sensible Temperature.	Constituent Temp. of Vap.	Elasticity.	State of Atmosphere.	Force of Evaporation.
0	80·	67·9	·673	Clear	327
5,000	64·4	*64·4	*·606	Cloudy	467
10,000	48·4	19·	·124	Clear	
15,000	31·4	16·	·112	Clear	
20,000	12·8	*12·8	*·100	Cloudy	80
25,000	− 7·6	−20·7	·027	Clear	
30,000	−30·7	*−30·7	*·020	Hazy	

The last division of this Table gives the relative force of evaporation at the different points, supposing the total effect, if unopposed and sudden, to be 1000, and the same numbers will represent the comparative amount of precipitation, at the several intervals of condensation, or the relative densities of the three clouds. In this manner the struggle between the elasticity of the steam and the condensing power of the cold is divided and moderated, and the whole process becomes so gentle as quietly to restore the balance of force and temperature, provided the counteracting cause be not of a permanent nature. The moisture falling gradually back into the excess of heat below, is converted into vapour of higher force, which pressing more upon the inferior strata, proportionately raises their densities.

From these considerations it would appear that in any single column considered by itself, clouds of greater or less densities, and evaporation of greater or less force at different heights, must be the consequence of a temperature decreasing in a more rapid progression than is due to the law of aqueous vapour.

While the atmosphere is in the state represented in Table XXIX., let us contemplate the effects of a general reduction of sensible temperature upon the constituent temperature and the different points of precipitation. We will suppose the fall to take place gradually, and to amount to 10 degrees. In the first place, the elastic force upon the surface will not be diminished, but will approach the point of precipitation within three degrees. A plane of condensation will be established between the surface and the height of 5000 feet. So, likewise, the vapour from 9000 to 14,000 feet will not be disturbed, but the second plane of condensation will descend from 18,500 feet to an intermediate position between that elevation and 14,000 feet. The shifting of these planes would not be sensible at the surface; for the light precipitations which would accompany their slow subsidence would be expended in equalizing the temperature.

We must next contemplate these phenomena, hitherto considered as confined to a single column, in connexion with adjacent sections. Let us take as an illustration the equatorial column of 80° temperature, in the state in which we have just considered it, and the adjoining one of 76°·8. The flow of the lateral currents may be determined by the following Table:—

TABLE XXX. *Showing the State of the Atmosphere occasioned by the intermixture of Lateral Currents.*

Height.	Latitude 10.				Latitude 0.			
	Sensible Temperature.	Constituent Temperature.	Elasticity.	State of Atmosphere.	Sensible Temperature.	Constituent Temperature.	Elasticity.	State of Atmosphere.
0	76·8	51	·388	Clear	80·	67·9	·673	Clear
5,000	61·1	48	·351	Clear	64·4	*64·4	·606	Clear
10,000	*44·9	45	·316	Cloudy	48·4	19·	·124	Clear
15,000	27·7	12	·096	Clear	31·4	16·	·112	Clear
20,000	9·3	9·3	·087	Cloudy	12·8	12·8	·100	Clear
25,000	−11·6	−32	·019	Hazy	− 7·6	−27·	·027	Clear
30,000	−35·	−35	·016	Hazy	−30·7	−30·7	·020	Clear

In this Table, the first point of condensation in the equatorial division, is supposed to take place at the height of 5000 feet, while at latitude 10 it is fixed at 10,000 feet: and it will be seen that up to the former elevation the vapour of the first column is of much greater elasticity and density than that of the latter; it will, consequently, flow laterally towards it with considerable force. No cloud will be formed as before, at the point of condensation, for the supply arising from the evaporation at the surface, will be carried off in a lateral direction. Nor would the transparency of latitude 10 be affected up to this height; for the current which it would receive would, in constituent temperature, still be below what its sensible heat would maintain. But above this line a dense cloud would be precipitated. A counter-flow of small extent towards the equator will be established at 10,000 feet; and above this, again, the pressure will return to the

first direction. The constituent temperature of the returning current, being below the temperature of the elevation, the transparency of the equatorial column will be preserved throughout. These lateral currents are supposed to take place under the same mechanical retardation as that of the ascending vapour.

It would be easy to multiply and vary these illustrations; but enough has been done to show generally that the necessary condition of transparency in any vertical section of an atmosphere of pure vapour, in which, from some extraneous cause, the temperature diminishes faster than the natural progression, is, that the quantity generated from the evaporation, necessarily accompanying such circumstances, should be carried off to adjoining regions.

Our hypotheses have hitherto been framed upon the assumption, that the sphere round which the aqueous atmosphere has been diffused, was covered with water, whence a continual supply of vapour would flow equivalent to every increase of temperature. Let us now suppose that water is only partially spread upon the surface, and that the uncovered portions are absolutely dry. Vapour, out of the contact of water, is affected in the same way as the permanently-elastic fluids, by variations of temperature; that is to say, it contracts or expands according to the same law for each degree of change, above its point of precipitation, by Fahrenheit's scale. If a current, therefore, were to pass over a dry space, heated to a degree higher than itself, the same changes in its constitution would take place, in miniature, as we have

already traced in the dry atmosphere. Its density upon the surface would diminish, while its elasticity would remain the same, and be increased at higher stations. The following Table presents us with the different degrees of elasticity in a column of the constituent temperature of 80° heated to 90°.

TABLE XXXI. *Showing the Effects of Expansion upon Vapour heated beyond its Dew-point.*

Height.	Elasticity.	Constituent Temperature.	Sensible Temperature.
0	1·000	80	90
5,000	·899	76·5	86·5
10,000	·808	73	83
15,000	·727	70	80
20,000	·653	67	77
25,000	·587	63	73
30,000	·528	60	70

Such modifications would necessarily ensue in the cases which have already been considered, of the constituent temperature falling below the sensible heat; but, by comparing this Table with Table XXIV., it will be seen, that the total effect at the greatest extreme does not exceed ·007 inches; and it will be unnecessary, in the general view which we are now taking of the subject, to introduce a correction to such a small amount.

In the case of vapour becoming heated in this manner, out of the contact of water, it may reach its point of deposition at a high elevation without producing any sensible cloud; for, although it would be slowly precipitated, it would be instantly restored to

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the elastic force by the excess of heat in the inferior strata; and no accumulation could be formed for want of supply from the dry surface below. A slight haziness might possibly be the result.

Let us now imagine a stream of vapour, of known elasticity, filtering its way laterally through the resisting medium which we have supposed to exist, (see *ante*, p. [illegible]) from the part of the sphere which is covered with water of a certain temperature, to another which is perfectly dry, and of equal or superior temperature. As it arrives at the latter point, it will diffuse itself equally over the dry surface, and its elasticity, being no longer [illegible] by an incumbent atmosphere of like [illegible], will be reduced, and it will assume that force which its diffusion will enable it to maintain. [illegible] elasticity, flowing into [illegible] already exists an atmosphere of [illegible] density to that of the [illegible] In Fig. XXXII. are represented two [illegible] the first incumbent [illegible] temperature of 70°, and the second [illegible] temperature of 30°. It is obvious [illegible] will flow into the latter, but will no [illegible] by its constituent temperature [illegible] will be gradually reduced to the [illegible] second column 32°. The elasticity, [illegible] column will rise with the increasing [illegible] the first.

TABLE XXXII. *Showing the Effects of the Diffusion of Vapour of High Elasticity from Water, over a dry Surface.*

Water.			Dry Earth.		
General Temperature	Constituent Temperature.	Elasticity.	General Temperature.	Constituent Temperature.	Elasticity.
70	60	·524	80	32	·200

A similar lateral diffusion will also take place with various degrees of force, according to the various balances of elasticity at different stages of the height; and, if the resistance of the opposing medium be supposed to decrease with the ascent, with the greater facility in the upper regions. The lateral and vertical diffusion both thus conspire to regulate the general tension of the vapourous atmosphere.

But the surface upon which an atmosphere of any particular density rests, may be neither of water, nor of perfectly dry earth, but we will imagine it to be earth differently imbued with moisture and variously heated:—then a partial supply of vapour, varying in quantity in different places but of the same degree of density, would take place, and clouds of more or less opacity would be formed, at corresponding situations, in the planes of deposition above. The following Table will tend to illustrate these positions.

TABLE XXXIII. *Showing that the Elasticity of Vapour, yielded by different Surfaces variously heated, is governed by the incumbent Atmosphere.*

Height.	General Temperature.	Water, Temperature 60·8.			Moist Earth, Temperature 70.			Dry Earth, Temperature 80.			Height.
		Constituent Temperature.	State of Atmosphere.	Force of Evaporation and Precipitation.	Constituent Temperature.	State of Atmosphere.	Force of Evaporation and Precipitation.	Constituent Temperature	State of Atmosphere.	Force of Evap.	
0	60·8	34	Clear	·368	34	Clear	·507	34	Clear	·786	0
5,000	44·6	31	Clear		31	Clear		31	Clear		5,000
10,000	27·9	28	Cloudy	{Density ·368}	28	Cloudy	{Density ·092}	28	Hazy ?		10,000
15,000	10·	− 6·4	Clear		− 6·4	Clear		− 6·4	Clear		15,000
20,000	− 9·4	− 9·4	Cloudy	·126	− 9·4	Hazy	·021	− 9·4	Clear		20,000
25,000	−31·2	−31·2	Hazy	·020	−31·2	Clear		−31·2	Clear		25,000
30,000	−55·9	−55·9	Clear		−55·9	Clear		−55·9	Clear		30,000

The same general temperature is here supposed to prevail for a moment in every part of an atmosphere, the vapour of which is every where of equal force; resting upon a surface covered with water in one part, with moist earth in another, with dry earth in a third, and varying moreover in heat in the three situations. The first point of precipitation is placed at 10,000 feet. The water upon which the first part of the column rests, is of the same degree of heat, as the general temperature at the surface; the force of evaporation is ·368, and as the supply is equal to the force, the density of the cloud is also ·368. The moist earth, upon which the second portion rests, is of the temperature of 70°, which makes the force of evaporation ·507: but less steam being given off from the earth than from the water, the quantity of the precipitation is proportionally diminished. It is calculated arbitrarily in the Table at one fourth. The dry surface, which supports the third portion, is heated to 80°, and yields no vapour: the evaporating force, which is equal to ·786, is wholly unapplied, and no cloud can therefore be maintained. The higher points are subject to the same modifications. The temperature of the evaporating surface regulates the quantity of water raised in vapour, the tension of the pre-existing atmosphere determines its elasticity.

We may here conclude the separate consideration of the properties of aqueous vapour, applicable to our design. It will be perceived that some particulars have necessarily been anticipated which would have been more consistent with the contents of the follow-

ing division; but the inquiry has been, as much as possible, restricted to the single object in view. It will, however, have been anticipated, that the mechanical retardation of the motions of the vaporous atmosphere, together with the forced progression of temperature, which have been so often referred to, belong to the state of mixture with the gaseous atmosphere; and we may now further connect the preceding remarks by observing, that, in the operations of the aqueous steam, a power is developed, as will presently be shown, fully adequate to produce the disturbances of temperature hypothetically proposed in the examination of the permanently-elastic fluid in the second part of this Essay.

PART IV.

ON THE HABITUDES OF AN ATMOSPHERE OF PERMANENTLY-ELASTIC FLUID, MIXED WITH AQUEOUS VAPOUR.

Having separately considered some of the properties of simple atmospheres of permanently-elastic fluid and of aqueous vapour, such as are most essential to the object of our inquiry, we may now proceed to investigate the compound qualities of a mixture of the two, and their mutual relations so combined.

The properties which each possessed in its separate state, will be retained in this connection unchanged, and the two fluids will only exercise a mechanical action upon each other when in motion. The particles of steam, in penetrating the interstices of the permanently-elastic fluid, experience, we may conceive, the same species of retardation as exists in their flowing through the pores of sand or cotton. It is not, however, intended to affirm that this is the exact kind of opposition which different gases and vapours present to each other in the act of diffusion; but it may be taken by way of illustration. That it is of a mechanical nature is probable from the law of diffusion being, as we have seen, dependent upon their respective densities.

The action of diffusion is also greatly promoted and accelerated by a concomitant circulation which takes place from the expansion of the permanent gas by the admixture of the lighter vapour, in conse-

quence of which it acquires a considerable ascensional power, which greatly promotes the process of evaporation, as will hereafter be shown. When a state of equilibrium is attained, this mutual action ceases, and the particles of each press only upon those of their own kind. There are, therefore, two principal points of view under which such a mixture may be regarded,—one, in which the particles are in a state of equipoise amongst themselves: and the other, where they are seeking an equilibrium by means of intestine motion. With respect to the first, there is no distinction between such a complete mixture and that of two or more permanently-elastic fluids; and it may be regarded in a mechanical point of view like a mixture of gases, as an homogeneous fluid.

We will now inquire what would be the natural state of such an atmosphere, surrounding a sphere of uniform temperature?

Before this question can be answered satisfactorily, we must consider what are the effects of mixing known measures of the gases, with vapour of different degrees of force. The first effect is increase of bulk, under equal pressure in the permanently-elastic fluid; not in proportion to the measure of vapour added to it, but in proportion to its elasticity. Thus, if we mix a cubic foot of dry air, of the temperature of 212° and of the elasticity of 30 inches, with as much steam as would rise in the space of a cubic foot at the same temperature, and consequently of the force of 30 inches, the mixture would occupy the space of two cubic feet; for 30 inches : 60 inches :: 1 : 2.

So also, if we mix a like measure of air, of the temperature of 32° and of the elasticity of 30 inches, with as much vapour as would be formed in the same space at the temperature of 32°, and, consequently, of the force of only 0·200 inch, the bulk of the gas will only be increased ·00666 of a cubic foot.

For 30·000 : 30·200 :: 1· : 1·00666

The ·00666 of a cubic foot (= 1·7 cubic inches) may be regarded as so much steam of the elastic force of 30·000 inches added to the cubic foot of dry air which has diffused itself through the whole space.

The case is exactly analogous to what would happen from the mixture of gases, of different degrees of elasticity. A cubic foot of air, of the elasticity of 30 inches, added to another cubic foot of the same elasticity, will have its volume doubled; but a cubic foot of air, of the elasticity of only ·200 inch, is only equivalent to 1·7 cubic inches of the elasticity of 30 inches, and being added to a cubic foot, of the elasticity of 30 inches, will only increase its volume ·00666 of a cubic foot.

The second result is, that the specific gravity of the gas is decreased; but not exactly in proportion to its expansion: for while the vapour dilates its parts, it adds its own weight to the mixture. But this weight, though increasing with the elasticity, being, in all cases, less than that of an equal bulk of common air, decrease of density must follow. The diminution becomes greater with every increment of temperature.

Let us imagine an homogeneous atmosphere of air, of the temperature of 77° and 30 inches pressure:

its specific gravity, compared to air at 32°, would be ·90626 : 1·00000. Let us suppose this to be mixed with an atmosphere of vapour of the same temperature, and ·910 inch force; the specific gravity of the mixture under equal pressure would be ·89312; its total pressure would amount to 30·910 inches; and its height would be increased from 28,775 feet to 30,260 feet. But, as we have seen before, the mean temperature of an homogeneous atmosphere must fall, in assuming that gradation of density which is essential to its natural state; the quantity of vapour must, therefore, suffer a proportionate reduction. If we were to assume the scale of decrease, represented in Table VII., for a temperature at the surface of 77°, the corresponding diminution of its force would be as follows:—

TABLE XXXIV. *Showing the small Amount of Vapour which could exist in an Atmosphere of Air of normal Temperature, supposing it saturated throughout.*

Height.	Temperature.	Elasticity.
0	77	·910
5,000	61	·542
10,000	45	·316
15,000	27·5	·171
20,000	9·3	·088
25,000	−11	·042
30,000	−35	·016

The average elasticity, therefore, of the vapour to this height, could not exceed 0·297 inch. We must further consider that the altitude to which we have

hitherto been conducted in our speculations, has comprised but two-thirds of the total height of our atmosphere; the remaining third may, without any risk of error, be considered, from the lowness of its temperature, to be totally free from vapour. The mean pressure, therefore, of steam, would thus be reduced to ·198 inch; and supposing such a state of circumstances to be possible, the barometer would only rise from 30 inches to 30·198 inches in the atmosphere surrounding a sphere of the temperature of 77°, by a change from absolute dryness to perfect moisture.

Nor would such a state of saturation constitute, by any means, a natural condition of such an atmosphere as we are contemplating. Even if a general mixture could be effected in the proportions which we have above imagined, the elasticity of the steam at the bottom of the column would be greater than the elasticity of that which the upper strata would confine; so that being urged upwards it would be condensed by the temperature of the air, which decreases faster than the progression due to the vapour, and the barometer would not rise to the height just stated.

A state of complete mixture, in which all the particles would be at rest amongst themselves, cannot, therefore, exist in the compound atmosphere; and it can only, consequently, be regarded in the second point of view distinguished above, namely, as in a state of intestine motion.

To place these particulars in a clearer light, let us trace the progress of vapour just beginning to form in

a perfectly dry atmosphere. For this purpose we will imagine the temperature of the sphere to be 77°. The first arrangement will be such as is represented under latitude 10, in Table VII. Let us now imagine water suddenly to overflow the surface; in which case evaporation will instantly commence. No atmosphere of vapour exists to impede its progress, the nascent steam will, therefore, merely assume the degree of tension necessary to overcome the resistance of the air which obstructs its motion. What this force may be, we have not, perhaps, sufficient *data* to determine. We must, for the present, fix it arbitrarily, and assume that, at the temperature of 77° and pressure of 30 inches, it amounts to ·200 inch. The constituent heat of vapour of this elasticity is 32°, so that at the height of about 13,500 feet it would meet with its point of condensation. An aqueous atmosphere of such degree of force being now established, fresh resistance to this amount is made to the progress of evaporation; and the elasticity of the rising steam must be doubled. Its constituent temperature is thus raised to 52°, and it cannot, therefore, pass the height of 7500 feet, without deposition. The resistance upon the surface now amounts to ·601 inch, to overcome which, vapour at 65° must be emitted. The first point of precipitation, in ascending from the surface, would thus be fixed at about 3600 feet. We may now further remark, that the diffusion of vapour does not cease at the height of 13,500 feet, to which point we had first traced it; but the mechanical obstruction is proportionably reduced, and it is carried by succes-

sive stages to more lofty regions, where its tenuity is so much increased that it speedily eludes all observation.

We have hitherto imagined the process of evaporation to be carried on by the power of diffusion only in a still atmosphere; but it is obvious that this would be greatly promoted by the convective power of air rising from a heated surface. The ultimate distribution of the vapour would be the same; but it would more quickly reach its different points of condensation; for it must be remembered that the air as it rises is subject to its own law of specific heat, and that its temperature must fall in a more rapid ratio than that of the steam intermingled with it.

With regard to the various points of condensation, it is probable, as was before remarked, in the atmosphere of pure steam, that at the commencement of the process no cloud would be formed at any of them. The process of evaporation would be so gentle under these circumstances, that little more than six grains of water would be raised per minute from the surface of a square foot; so that, as the gradual precipitation of this quantity took place between the different stages, it would instantly be re-dissolved by the excess of heat of the medium into which it would naturally incline to fall. The circulation thus becomes a process of equalization, by which the temperature of the upper regions is raised: the heat which is abstracted below by evaporation is evolved by condensation, the pressure of the vapour is increased, and all the changes tend to that distribution of heat which we formerly contemplated as the natural state of an unmixed atmosphere of steam.

The average quantity of vapour, which would exist upon the hypothesis which we have just assumed, while the atmosphere maintained its proper progression of temperature, may be roughly approximated as follows: a stratum, of the force of ·616 inch, extends to the height of 3600 feet; another, of the force of ·401 inch, reaches 3900 feet further; a third, of only ·200 inch, stretches almost as far as both the former together; making a total of 13,500 feet. The mean, therefore, to this point is nearly

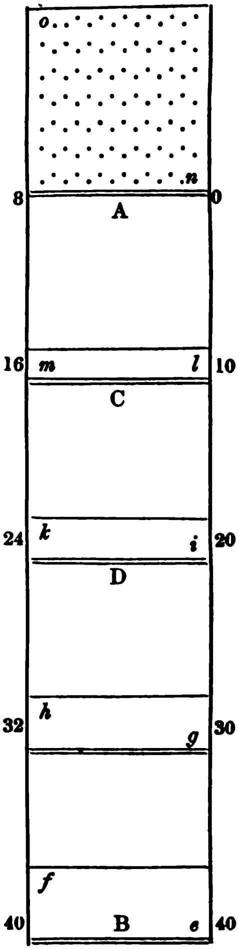
$$\frac{\cdot 616}{4} + \frac{.401}{4} + \frac{\cdot 200}{2} = \cdot 354 \text{ inch.}$$

For the further distance of 17,500 feet, we cannot greatly err in taking ·064 inch, as the mean elasticity, making the average to the height of 31,000 feet, ·209 inch. One-third of the atmosphere beyond this being considered free from vapour, reduces the mean to ·139 inch. Moreover, the mean pressure of the vapour mixed with a gaseous atmosphere is by no means equal to its elastic force, on account of the expansion of the latter, but may be so assumed to illustrate the argument.

The following diagram may possibly tend to elucidate the effects of an unequal addition of matter, and of unequal expansion in various parts of the same column of fluid, without reference to its elasticity.

Let A B represent the column whose height and weight we will call 40. Its four sections A B C D are each equal to 10. Let us suppose an addition of matter to take place in B, *e f* equal to 4; in D, *g h* equal to 3; in C, *i k* equal to 2; and in A, *l m* equal to 1. The total increase of weight and pressure at the bottom will be 10, or one-fourth of the original

Fig. 9.



amount: the same as if the total amount had been equally distributed throughout the mass, or added at once to the top of the column, as *n o*.

Again—if in the same column an unequal expansion were to take place in the four sections, *e f* = 4, *g h* = 3, *i k* = 2, and *l m* = 1, the total increase of bulk *n o* would be the same as if the expansion had every where been equal, and, the weight at the base remaining the same, that of the sections would be altered from 0, 10, 20, 30, 40, to 8, 16, 24, 32, and 40.

In the case of the atmosphere, which we are considering, both these changes are combined: the barometer rises at the surface of the sphere, from the weight of the additional aqueous matter; and the relative weights of the several upper strata are still more materially augmented by the expansion. The following Table exhibits the state of the barometer at equal altitudes before and after the admission of vapour, in an atmosphere surrounding a sphere of the uniform heat of 77°; together with the temperature appropriate to the elevation and the dew-point upon the assumption just made.

TABLE XXXV. *Showing the State of the Barometer, at equal Altitudes, in an Atmosphere of Air, before and after the Admission of Vapour.*

Height in Feet.	Temperature.	Barometer. Atmos. without Vapour.	Barometer. Atmos. with Vapour.	Dew-Point.
0	76·8	30·000	30·139	65
5,000	61·1	25·214	25·348	52
10,000	44·9	21·193	21·318	32
15,000	27·7	17·812	17·928	9
20,000	9·3	14·970	15·079	0
25,000	−11·6	12·583	12·682	−35
30,000	−35·	10·578	10·667	−35

Such, then, would be the new state of things, from the admission of water to the surface of the sphere of uniform temperature; a state, however, which, notwithstanding the equality of the superficial heat, could not be one of permanent rest. A perpetual struggle would ensue between the temperature due to the density of the air, and the constituent temperature of the vapour, accompanied by perpetual evaporation below, and condensation above. No winds or lateral currents would be established, but there would be an increasing circulation in a vertical direction.

It will be observed, that the total alteration of pressure is but small, even in the almost extreme case which has been selected; it is in the unequal distribution, and its consequent effects, that we must seek for the principal influence of vapour in the mixed atmosphere. The elasticity of the vapour at the surface of the sphere is no guide to the mean pressure of the total aqueous atmosphere; nor by deducting the amount of that elastic force from the total atmospheric

Table XXXVI. *Showing the Specific Gravity, Ela*

Height.	Poles.					Latitude		
Feet.	Total Pressure.	Pressure of Vap.	Specific Gravity.	Temp.	Dew Point.	Total Pressure.	Pressure of Vap.	Speci Gravi
0	30·000	·044	1·06666	0	− 11	30·000	·047	1·060
5,000	23·597		·86935	− 18		23·652		·865
10,000	18·587		·70856	− 37		18·630		·706
15,000	14·591		·57752	− 58		14·642		·576
20,000	11·411		·47071	− 82		11·484		·470
25,000	8·900		·38365	−109		8·965		·384
30,000	6·906		·31270	−140		6·978		·313

Height.	Latitude 40.					Latitude		
Feet.	Total Pressure.	Pressure of Vap.	Specific Gravity.	Temp.	Dew Point.	Total Pressure.	Pressure of Vap.	Speci Gravi
0	30·000	·237	·96358	48	37	30·000	·375	·9346
5,000	24·072	·139	·80230	31	22	24·215	·221	·7824
10,000	19·336	·068	·66800	14	2	19·531	·112	·6550
15,000	15·525	·037	·55629	− 4	− 14	15·739	·046	·5485
20,000	12·409		·46273	− 24		12·673	·034	·4585
25,000	9·915		·38489	− 47		10·162		·3832
30,000	7·852		·32016	− 62		8·135		·3203

pressure do we obtain, as has been supposed, the simple pressure of the dry gas; for it must be remembered, that, from the difference of their specific gravities, the principal effect of mixing vapour with an unconfined dry gaseous atmosphere is the expansion of the latter, which, considered alone, like the expansion of heat in a column of air, will cause a different distribution of weight amongst its upper horizontal sections without proportionately disturbing the total pressure at its base.

Changing now our hypothesis of the sphere of equal temperature, for that of the sphere of unequal temperature, increasing from the poles to the equator, we will again assume, that the barometer stands every where at the same height upon the surface; which height we will suppose, as before, to be 30 inches. The state of the vapour in the different columns of the mixed atmosphere, is to be imagined to be in the same proportion as in the atmosphere which we have just been considering, that is to say, its constituent temperature, at the surface of the sphere, is to be within 11° of the temperature of the several zones. The whole arrangement is thus represented in the annexed Table (XXXVI.):

By comparing this synoptic view with that presented by Table VII., it will be seen that the specific gravity and elasticity of the air are but very slightly affected by this intermixture of aqueous vapour; so slightly, indeed, that the course and velocity of the currents, as represented in Table VIII., may be considered, without any chance of disturbing our main argument, as unaltered; and their balance to be that

by which the barometer is maintained at an unvarying height. It will also be remarked, that while the great aërial ocean is divided into two distinct strata, flowing in opposite directions from north to south and from south to north, the aqueous part, which is nearly confined to the lower current, presses in a contrary direction. The adjustment of these particulars remaining as now supposed, the compensating winds flow on, in the courses which have been described, and the balance remains undisturbed.

The admixture of vapour, which we have hitherto considered, has not yet affected the gradation of temperature, resulting from the decreasing density of the atmosphere in its upper parts; the process of evaporation, however, which has been described, must, in time, necessarily induce such an alteration. The steam, as it reaches its point of condensation, must give out its latent heat, but even in the act of precipitation, combines with a fresh proportion, again ascends, and again evolves it in the middle regions. It may thus be considered as carrying heat from the surface of the sphere to higher strata; and it is obvious how a considerable section of any one column may thus have its temperature equalized and fully saturated with aqueous particles. The latent heat of steam has been proved to be about 970° Fahr.; and it is known that whatever be its density, or the temperature at which it is produced, the amount differs little from this estimate. The condensation, therefore, of a pound of steam, of any degree of elasticity, would be adequate to raise a pound of water 970°. The capacity of atmospheric air, of mean density, for heat, compared

to that of water, is as 0·2669 to 1; therefore the same quantity of heat which would raise a pound of water 1°, would raise a pound of air 3°·7. The condensation of a pound of steam would therefore elevate the same weight of air to 3589°. A pound of air is equal to about eleven cubic feet; so that the evolution of heat from the condensation of a pound of steam would be sufficient to raise the temperature of 3657 cubic feet of air 10°. The currents thus become affected both by the expansive powers of the vapour and of the extricated heat—causes, the influence of which, so applied, must be partial, and cannot reach the higher regions. The unequal action must produce a fall in the barometer, as has been before explained.

As, on one hand, this effect upon the barometer is produced by the augmentation of the aqueous vapour; so, on the other, a rapid increase of the latter may be produced by a decrease of pressure mechanically brought about. The resistance of the air to the diffusion of the vapour will of course be increased when the two are moving in opposite directions. When this opposition is stopped, as it soon is, by a trifling fall of the mercurial column, the vapour will rush forward with its whole force, retarded only by its filtration through the quiescent air; and the temperature of the higher latitude being unable to support its elasticity, precipitation must follow. From the operation of these causes, the temperature of that latitude is partially affected, the density of the air is still further reduced, and the aërial current is reversed. The course of the vapour is thus greatly accelerated, and abundant precipitation will follow.

Neither must we here exclude from our consideration that vertical circulation of the air to which we have before referred, as resulting from the ascent of the strata heated by the surface of the sphere, and their descent after cooling in the upper regions. It is obvious how the evaporation must be thus accelerated, and how the vapour formed in the hotter regions must be transported into the upper current and precipitated from it upon the colder latitudes of the sphere.

Indeed there can be little doubt that the first admixture of the vapour itself with the lower stratum will give it a mechanical tendency to rise, which will greatly assist the act of evaporation; and there is reason to think, as we shall hereafter show*, that the amount of evaporation experimentally determined by Dr. Dalton, in calm weather, greatly exceeds that which would result in a confined atmosphere, where this mechanical action would be impeded.

The progress of the precipitated moisture, from the time when its first streaks would visibly shoot across the air, to the time when it would descend in rain upon the globe, is not without its interest. In proportion to the density of the vapour, no doubt, must be the magnitude of the condensed particles. When first formed in the higher elevations, the cloud would probably assume a light *cirriform* appearance; in lower regions the precipitation would be more dense, and the attraction of aggregation stronger; the mass would subside gently to a lower station, where the density of the air would oppose a greater resistance

* See Essay upon Hygrometry.

to its descent. Here, in a higher temperature, the cloud would again begin to be dissolved, and assume a rounded and compact form; and thus the equalization of the temperature, and the diffusion of the vapour, would be carried on from several points at once. The different beds would obey the impulse of the winds, and, as they sailed along, would enlarge the circumference of their action: till, at length, the natural equilibrium of the atmosphere being no further curbed, the precipitations would increase, the strata of the clouds inosculate, and the air no longer buoy up their load.

It is also worthy of observation, that when the natural progression of the gaseous atmosphere has been thus upset, and the progression due to an atmosphere saturated throughout with vapour and moisture prevails, that the amount of precipitation collected at different heights would vary, and would decrease from the surface of the sphere upwards. The drops of water first formed would necessarily proceed from the colder regions; and, unlike the air in a similar descent, would not augment their temperature from any change in their specific heat. They would carry their low temperature with them into the strata of hot vapour below, and would thus gradually condense it upon their surfaces, and increase their volume in their progress to the ground.

It will be convenient here to subjoin a synoptic view of the force of the aërial current, and the counter-pressure of the vapour in a mixed atmosphere, surrounding a sphere unequally heated in the manner already set forth.

TABLE XXXVII. *Showing the Force of the different Currents in a mixed Atmosphere of Air and Vapour, between the Poles and the Equator.*

Height.	Latitudes 90 and 80.		Latitudes 80 and 70.		Latitudes 70 and 60.		Latitudes 60 and 50.		Latitudes 50 and 40.	
	Wind.	Vapour.	Wind.	Vapour.	Wind.	Vapour.	Wind.	Vapour.	Wind.	Vapour.
0	+·178	−·003	+·387	−·010	+·575	−·028	+·810	−·049	+1·034	−·103
5,000	+·057		+·191		+·281	−·014	+·375	−·032	+ ·570	−·060
10,000	+·019		+·048		+·045		+·112		+ ·217	−·023
15,000	−·023		−·063		−·093		−·084		− ·035	
20,000	−·069		−·112		−·185		−·149		− ·239	
25,000	−·078		−·152		−·240		−·272		− ·307	
30,000	−·095		−·161		−·204		−·321		− ·322	

Height.	Latitudes 40 and 30.		Latitudes 30 and 20.		Latitudes 20 and 10.		Latitudes 10 and 0.	
	Wind.	Vapour.	Wind.	Vapour.	Wind.	Vapour.	Wind.	Vapour.
0	+·854	−·138	+·648	−·132	+·447	−·109	+·208	−·082
5,000	+·454	−·082	+·392	−·107	+·282	−·073	+·118	−·042
10,000	+·215	−·044	+·165	−·050	+·159	−·038	+·053	−·029
15,000	+·031	−·009	+·038	−·022	+·036	−·019	+·008	−·013
20,000	−·131		−·024	−·012	−·068	−·018	−·045	−·007
25,000	−·196		−·128		−·074		−·054	
30,000	−·291		−·170		−·090		−·070	

Doubts have been expressed above, whether we have sufficient *data* to determine the amount of the resistance which the pores of the gaseous constituents of the atmosphere offer to the passage of vapour in motion. Experiments certainly are wanting to elucidate this relation, but some recent ones will be hereafter detailed which bear upon the point. The observations of Dalton throw some light upon the subject. The resistance alluded to may be regarded as two-fold; first, in connexion with the permanently-elastic fluid at rest, and secondly, in motion.

With regard to the state of rest, the opposition with which vapour passes through air is, probably, in inverse proportion to its density.

With regard to the state of motion, a breeze in opposition to the stream of vapour, must retard its progress as much as one of the same velocity in the same direction favours it. Much obscurity envelopes this inquiry from the vagueness of the terms hitherto employed in denoting the velocity of the air. Dr. Dalton has determined that the rate of evaporation in a perfect calm being denoted by 120, that of a brisk wind is 154, and of a high wind 189. The retardation of opposing currents of the same respective forces may therefore be reckoned in proportion.

Some important conclusions follow from these propositions, however wanting they may be in precision. It is impossible, in the present state of our knowledge, to determine the absolute velocity with which vapour travels under any given circumstances; but the relative ratio of velocities of different parts of the same column may be approximated. Thus, taking latitude 30,

laid down in the last Table, the current which blows in the direction of latitude 40, may be deemed high, and retards the motion of the vapour towards latitude 20 accordingly. At the height of 10,000 feet the density of the air is reduced one-third, and the velocity is consequently doubled; to which we must also add, that the opposing current at the same elevation declines in strength, whereby the force is again increased in the proportion of 189 to 154. More vapour, therefore, probably would pass at this elevation than at the surface, although its excess of elasticity is only ·044 inches at the former station, and ·138 inches at the latter. Whenever a deep stratum of air has had its temperature and vapour equalized in the manner before described, it is easy to conceive that the aqueous atmosphere may travel in its upper parts with considerable velocity, in a course directly opposed to the wind at its lower. The approximation may be carried a little further, perhaps, as follows. The effect of a brisk wind in accelerating evaporation, is equal to an increase of about three-tenths of the elasticity; that of a high wind to six-tenths. The retarding influence of the polar current, in its regular state, may therefore be apportioned to the different latitudes in Tables XXXV. and XXXVI., as follows:—From the poles to latitude $80 = \frac{1}{10}$ of the elasticity, to lat. $70 = \frac{2}{10}$, lat. $60 = \frac{4}{10}$, lat. $50 = \frac{5}{10}$, lat. $40 = \frac{6}{10}$, lat. $30 = \frac{5}{10}$, lat. $20 = \frac{3}{10}$, lat. $10 = \frac{2}{10}$, and from lat. 10 to the equator $\frac{1}{10}$. The following Table, then, represents the efficient force of the vapour in a lateral direction, calculated for the surface of the sphere, and for the altitude of one-third the density.

TABLE XXXVIII. *Showing the efficient lateral Force of Vapour between the Poles and the Equator at the Surface of the Sphere, and at the Altitude of one-third the Density.*

	Latitudes 90 and 80.		Latitudes 80 and 70.		Latitudes 70 and 60.		Latitudes 60 and 50.		Latitudes 50 and 40.	
Height.	Balance of Force.	Effects of Wind and Density.	Balance of Force.	Effects of Wind and Density.	Balance of Force.	Effects of Wind and Density.	Balance of Force.	Effects of Wind and Density.	Balance of Force.	Effects of Wind and Density.
0	−·003	−·002	−·010	−·008	−·028	−·017	−·049	−·025	−·103	−·042
10,000	−·001	−·002	−·004	−·008	−·008	−·017	−·012	−·026	−·023	−·045

	Latitudes 40 and 30.		Latitudes 30 and 20.		Latitudes 20 and 10.		Latitudes 10 and 0.	
Height.	Balance of Force.	Effects of Wind and Density.	Balance of Force.	Effects of Wind and Density.	Balance of Force.	Effects of Wind and Density.	Balance of Force.	Effects of Wind and Density.
0	−·138	−·069	−·132	−·093	−·109	−·088	−·082	−·074
10,000	−·044	−·072	−·050	−·090	−·038	−·070	−·029	−·058

I must here repeat, that these Tables are not meant to impose an air of precision upon the subject, which the present state of our knowledge does not warrant; but to assist our conceptions of the general effects of so many conflicting causes. The last Table will give some idea of the retardation of force in the vapour, occasioned by the wind at the surface of the sphere, and also of the increase of velocity occasioned by diminished pressure in the upper regions. It is easy to understand that, whenever the aërial current coincides with the direction of the vapour, the progress of the latter is accelerated in the same proportion.

The permanency of the barometric pressure on the surface of the sphere is dependent, as we have seen, upon the equal balance of the aërial currents, its fluctuations have been traced to the destruction of this equipoise, by unequal and local expansions and condensations. One of the chief causes of these latter, there can be no doubt, is the increase and the decrease of the aqueous vapour, counteracting the natural progression of temperature by the heat evolved in its condensation; but there is another, to which no allusion has yet been made, which must necessarily be powerful in this operation. It has hitherto been supposed, for the sake of simplifying the subject, that the source of heat has been in the sphere itself; and that all the regular changes of temperature have emanated from its surface. This so far agrees with the condition of the atmosphere of the earth, with which it is our final object to identify our various hypotheses; for

while in a transparent state, the sun's rays pass through the air without materially affecting it, and expend their energy upon the surface of the globe. But, if the atmosphere become cloudy and opaque, the rays of heat, emanating from an external source, are in great part absorbed before they reach the surface, and an increase of temperature and elastic vapour must take place in the middle regions. Another source of partial and powerful expansion is here disclosed.

To this we may also add, the property which the clouds possess, of preventing the radiation of heat from the surface beneath them, and the greater conducting power of damp than of dry air.

Amongst the literally numberless modifications of circumstances to which an atmosphere of the nature we have been considering is liable, there are yet two or three to which it will be necessary shortly to refer. The surface of the sphere has hitherto been chiefly considered as perfectly plane, and either thoroughly dry or everywhere covered with water; let us now contemplate it as covered with water to the extent of three-fourths of its superficies, and the remaining fourth of dry earth, uneven and intersected by eminences. This intermixture of land and water at once introduces inequalities of temperature of a different character from those that have been hitherto considered. They arise chiefly from the greater rapidity both of heating and cooling in the dry surface dependent upon the peculiar constitution of the watery element. It will not be essential to our present pur-

pose to trace them into details. As the processes by which their impressions are communicated to the incumbent air are slow and gradual, they mostly affect the different columns in an equable manner; so that their influence upon the currents resolves itself into the cases which have been already proposed, of total and regular expansion. With respect to the vapour, however, the case is different. It is evident, from principles before established, that the parts of the atmosphere which are immediately over the dry spaces will not remain free from its admixture; for the elasticity of the surrounding medium will soon supply the vacuum. The rapidity of this equalization will depend upon the mechanical obstruction of the air being increased or diminished by adverse or favourable currents. When once diffused over the land it would be more subject to condensation, and the amount of precipitation must be restored from the expanse of waters.

It is not unimportant to remark, that the circulation of the atmosphere which we have pointed out, from either pole to the equator and back again from the equator to the poles, virtually divides its mass into two almost independent halves; and if we could imagine a wall or a chain of nearly perpendicular mountains rising from the equator to the altitude of the atmosphere itself, it would scarcely interfere with the ascensional force of the air on its two sides, or with the compensating currents by which its equilibrium is maintained. We might even conceive it possible that an atmosphere of lighter matter, such as hydrogen, might exist upon the southern side

of the equator, and an atmosphere of common air on the northern, without any general interference of the two. Diffusion would slowly take place at the vertical plane of their junction, but the process of interpenetration would be slow compared with the opposite mechanical movements which would tend to keep them separate.

The lighter atmosphere of the southern regions rising at first from the same barometrical pressure as the denser atmosphere of the northern by which it is bounded, would, however, ascend by a different gradation of densities to a greater height, and would, to a certain extent, overflow the latter and cause an increase of pressure upon its base. A permanent rise of the barometer in the one hemisphere, and an equivalent fall in the other, would measure the amount of this disturbance.

We can more easily conceive that in the two polar hemispheres the distribution of land and water may be so unequal as that in the one the atmosphere may rest almost wholly upon land, and in the other upon water. The ultimate result would be, that in the latter case the damp atmosphere, expanded and warmed throughout its mass by the gradual convection of heat to its upper strata, by the successive evaporations and condensations which would be in continual progress, as we have seen, would approximate in its character of levity to the atmosphere of hydrogen which we have just imagined, and a similar adjustment of barometric pressure would take place in the comparatively dry and moist atmospheres.

Unevenness of surface would also tend to modify the atmosphere in an inferior degree. Any elevation would obviously partake of the temperature due to the stratum of air into which it rose; but the action must be reciprocal, and as the heating surface is raised to higher regions, those regions must be proportionally and unequally affected by its elevation.

But these and similar particulars belong more especially to the history of the terrestrial atmosphere; and we are now arrived at that point where we may discontinue the synthetical process, and proceed to prove the accuracy of our deductions by the analysis of the phenomena presented to us in nature.

We will close this division of our subject with one important conclusion, which we may derive from the preceding argument, viz., that the greater part, if not all, the perturbations of our atmosphere arising from irregularities of heat, moisture and surface, have their origin in and primarily affect its lower half, which, as we have seen, cannot greatly exceed a tenth of its whole height; the upper half will be principally affected by secondary adjustments, and in its unopposed course from the equator to the poles, may be regarded as the great fly-wheel by which the motions of the aërial machine are equalized and regulated.

PART V.

EXAMINATION OF THE PARTICULAR PHENOMENA OF THE ATMOSPHERE OF THE EARTH*.

In entering upon our analysis of atmospheric phenomena, we are at once met by a difficulty which will perpetually recur, and will greatly retard our progress,—namely, the want of accurate and trustworthy measurements. In Meteorology, the necessity for the closest attention to the construction, graduation, and location of instruments,—of systematic, and corresponding observations,—and of the most minute details of associated circumstances, is only now beginning to be felt by observers; and the consequence is, that for want of such precautions, much labour has been

* Meteorological Maps of the Atlantic and Pacific Hemispheres have been constructed to accompany this Essay, in which it has been attempted to present to the eye a connected view of the leading particulars of the different climates of the globe. The boundaries of the trade winds, the monsoons, and other periodical winds, have been laid down, and those of the principal currents of hot and cold water. The mean and extreme temperatures of the different latitudes, at the level of the sea, are indicated both by lines and figures; and an attempt has been made to represent the line of perpetual congelation in the atmosphere from theory, and to compare it with observation. It is hoped and believed that frequent reference to them will greatly assist in forming a correct notion of the connection of the phenomena about to be discussed in the text. The particular description of the maps will be given hereafter separately.

lost, and in many cases the work of observation has to be begun anew. This disadvantage has been strongly pointed out and felt; and the unexceptionable observations which are now being made in the different Observatories which have been lately established will leave nothing to regret by those upon whom the task of discussion will hereafter fall.

§ 1. MEAN BAROMETRIC PRESSURE.

1. The first fact which we would wish to establish, as being the first to which our hypothesis has directed our attention, and which constitutes the foundation of all our reasoning, is the general equality of the mean height of the barometer at every part of the globe, at the level of the sea.

Equality of pressure is one of the fundamental laws of hydrostatics; and consequently we have seen that it is one of the first conditions of an atmosphere at rest. We have also concluded that when acted upon by disturbing causes, the restoration of the equilibrium is the object of all the motions excited. When the cause is general, permanent, and equal, the effect produced is exactly adequate to maintain an unfluctuating balance; and equality of pressure is attained and preserved by means of regular currents. When the cause is local, transient, and unequal, there is not time to effect a general adjustment, and partial disturbances are the consequence; but the local effects are equivalent to undulations of the medium, and must be always as much in excess on one side as they are

in defect on the other, and oscillate on either side of the same point of equilibrium. The balance of fluctuations will therefore still exhibit equality of pressure.

The disturbing cause, however, may be local and partial, but permanent; and this permanent disturbance, by its continual conflict, may produce a permanent inequality in the general pressure. In Tables XIII., XIV., and XV. of the preceding illustrations, we have shown how a fall of the barometer at the surface of the earth may be effected by gradual small increments of temperature in the upper parts of the aërial column, such as must be produced by the evolution of the latent heat in the condensation of the intermingled steam. This local deficiency of pressure must obviously be accompanied by an equivalent excess and an equivalent rise of the barometric column in neighbouring parts, over which the expanded air has flowed. These inequalities will speedily adjust themselves to the general mean by the action and reaction of lateral currents, when the temporary interference of the local disturbance is withdrawn, or the cessation of precipitation allows the atmospheric column to return to its normal state. Should the disturbing cause, however, continue to act—should the precipitation of the vapour be permanent—the pressure of the column would be permanently decreased, and the lateral currents would be permanently adjusted to the new combination of forces.

Barometrical observations, made at every accessible part of the globe, prove that the annual mean

height of the mercurial column does not vary to any considerable amount at any station, whether at the level of the sea or at any elevation above it; and till very lately, it was generally believed that the mean height, at the former level, was everywhere equal, and was as nearly as possible 30 inches. Recent and more careful observations, however, indicate that the equatorial mean pressure is uniformly less than that at and beyond the tropics. This was first noticed by Baron Humboldt, and has received confirmation from observations made both on land and sea by Schouw, by Sir John Herschel, on his voyage to and from the Cape, and by other observers, on both the Atlantic and Indian Seas. Although the data are not yet sufficient to determine, with any precision, the difference for different degrees of latitude, there is reason to conclude that in the northern hemisphere the mean pressure of the equatorial regions, for about 10° latitude, is 29·842 inches. It then gradually increases, till between 30° and 40° it attains its maximum of from 30· to 30·078 inches. It then again decreases, and at about 50° only amounts to 29·92 inches.

These variations from absolute equality of pressure can only be regarded as small when we compare them with the energy of the forces which at times disturb the hydrostatic balance; and for them our theory will account by the permanent operation of sufficient causes. The decreased height of the barometer probably indicates the ascensional force of the heated air between the tropics, which ascent is thus shown to precede, in some degree, the compensating cur-

rent, which tends to restore the balance; and the momentum of the descending currents, cooled in their passage towards the pole, conflicting with the polar current, produce an accumulation of the atmosphere and an increased pressure at the point where they intermingle, or between the degrees of 30 and 40 latitude.

The same general results are obtained upon comparing the less numerous observations which have been made in the southern hemisphere; and Sir James Ross, in his recent voyage to the Antarctic Regions, has established the fact that from the 40th degree of south latitude the mean height of the barometer decreases to the 78th degree, or the highest latitude which he attained. This comparative levity of the atmosphere of the southern hemisphere of our globe may probably be accounted for by the permanent expansion produced in it by the perpetual rise and precipitation of aqueous vapour from a surface almost covered with the sea, and differing in this respect so materially from the corresponding dry latitudes of the northern hemisphere. A deficiency of pressure of the same nature, though to a less amount, has been observed on the Pacific Ocean, as compared with the corresponding parts of the Atlantic. The mean barometer is only 29·71 inches on the former, while it is 29·85 inches on the latter. An excess of water over the land characterizes even the North Pacific, similar to that which distinguishes the southern and the northern hemispheres; as will be obvious by casting an eye upon the maps.

2. That the mean density of the atmosphere de-

creases in a geometrical progression for heights, taken in arithmetical progression, is another fundamental fact which has been established with the greatest precision.

The density of the air is the result, as has been already stated, of the action and reaction of its gravity and elasticity; between the two forces there must be an exact balance. If we suppose the atmosphere divided into strata of equal weights from the top, the first stratum will press downwards with the whole of its own weight, and nothing more; the second will press downwards with its own weight and with the weight of the first in addition; a third will have to support its own weight and the weight of the two preceding; a fourth will be compressed by three, and so on—each stratum being compressed by the weight of all above it. The thicknesses of the strata, which will be in inverse proportion to the compressing force, and under the same compression would be all equal, will thus of necessity present an increasing geometrical series. The following Table shows, in a striking manner, the result of this law:

TABLE XXXIX. *Showing the Geometrical Progressions of the Volume and Elasticity of the Air for Heights taken in Arithmetical Progression.*

Height in Miles.	Volume.	Height of Barometer.
0·000	1	30·000
2·705	2	15·000
5·410	4	7·500
8·115	8	3·750
10·820	16	1·875
13·525	32	0·937
16·230	64	0·468

Now the force of gravity being exerted in a perpendicular direction, any increase or decrease in the two antagonist forces must instantly pervade the whole of the vertical column in which it takes takes place; so that under every circumstance of disturbance, the geometrical progression of the density will be maintained. This property is so invariable, that it has been applied with great advantage to the measurement of heights by the barometer.

We have already noticed that the subtangent of the common system of logarithms ·4342945 is, as nearly as possible, 1,000 times the height of the homogeneous atmosphere at the temperature of 32°, expressed in fathoms, and which is equivalent to the barometric column of 30 inches. The difference of the logarithms, therefore, of the height of the barometer at the bottom and the top of any height, divided by 1,000, will give the measure of the height in fathoms, provided the air be at the temperature of 32°, and contain no vapour. The height of the homogeneous atmosphere will obviously vary with variations of temperature and moisture; but the approximative height thus obtained may easily be corrected, by ascertaining as nearly as possible the mean specific gravity of the column of air between the two stations; for the approximative height will be to the correct height in proportion of the specific gravity to 1,000*.

The method of correcting the height of the mercurial column for the temperature, usually adopted

* See the Essay upon Hygrometry.

in barometrical mensurations, is by no means correct. It consists in estimating the temperature of the air, by taking an arithmetical mean between the heights of the thermometer at the upper and lower stations, upon the supposition of the uniform diffusion of heat in the column intercepted between them. Although its adoption, in cases of moderate elevation, is attended by no very sensible error, its insufficiency is very manifest at great altitudes. M. De Luc, when he proposed this correction, was sensible of its imperfection; and General Roy observes, that "one of the chief causes of error in barometrical computations proceeds from the mode of estimating the temperature of the column of air from that of its extremities; which must be faulty, in proportion as the height and difference of temperature are great." The preceding speculations naturally suggest some ideas upon this subject, which it would occupy too much time to attempt to develope here. It is sufficient for our present purpose, to establish that some correction for temperature is necessary.

I shall subjoin the results of some of the most accurate measurements of heights in different parts of the world, conducted both by the geometrical and barometrical methods, to show how close is the agreement between them, and the certainty of the law of geometrical progression in the atmosphere, upon which the barometrical calculation is founded.

More extended Tables will be hereafter given, to exhibit the effects of disturbing causes, but from which the same general conclusion may be derived.

TABLE XL. *Comparison of Geometric and Barometric Measurements of Heights.*

Observers.	Place of Observation.	Lat.	Long.	G. Height in Feet.	B. Height in Feet.
Webb . .	Gunna Nath, Stockdale .	29° 45′ 56″	79° 30′ 29″	6,828	6,831
	Bagha Ling, Temple . .	29° 47′ 30″	80° 2′ 27″	7,646	7,635
Borda . .	Teneriffe . . .	28° 30′	16° 13′	12,188	
Von Buch	Ditto	....	....	....	12,131
Buckle .	Sugar Loaf, Sierra Leone	8° 29′ 40″	13° 15′	2,493	
Sabine . .	Ditto	....	....	....	2,521
Sabine . .	Spitzbergen. .	78°	10°	1,644	1,640

3. The barometer, at the level of the sea, is but slightly affected by the annual or diurnal fluctuations of temperature.

This will be apparent from every register, whose mean observations are consulted with this view. The vicissitudes of day and night, and the changes of the seasons, are produced by very gradual processes of heating and cooling; the alterations of temperature have time to pervade the whole column almost equally, and the balance is nearly preserved by the equalization of the effect. The heating power, in general, being the surface of the earth, the arrangement is in the most perfect form for effecting this end. The air above becomes cooled from its position, and of greater density than is due to its elevation; while that below is expanded by its contact with the heated body, and a rapid interchange of situation must necessarily ensue.

The cooling of the atmosphere by radiation must be distinguished from that decrease of temperature

which arises from its increased capacity for heat. The amount of the latter is definite for the height, and it is a constituent element of the density due to the elevation; but by the former power, the air is cooled below this standard temperature, and becomes in its successive strata specifically heavier. That this emission of heat into space is constantly going on, is evident from the permanency of the mean temperature, which, notwithstanding the constant accession which it receives from the sun, ever remains the same.

But although any undue acceleration of either of the great principal currents is prevented by this mixture, yet a tendency has been observed in the barometer to oscillate in a regular manner at particular hours of the day, to which we will refer more particularly hereafter.

4. The barometer, in the higher regions of the atmosphere, is, however, greatly affected by the annual and diurnal fluctuations of temperature.

This observation is easily confirmed in various ways; but for the present, I shall refer for its correctness to those valuable registers which are simultaneously kept at Geneva, and the summit of Mont St. Bernard, and published in the *Bibliothèque Universelle de Genève.* Upon the average of four years, at those stations, I find, that from sun-rise to 2 P.M., the upper barometer gains upon the lower ·037 inch, and from winter to summer ·260 inch. This will be deemed direct and satisfactory proof of the proposition, although the places where the observations were made

are not exactly suited to exhibit the fact in its most striking form. The city of Geneva is situated at a great height above the level of the sea, and must, therefore, itself partake of the barometric change referred to. To this we may add, that experiments, made upon elevations of the surface of the earth, can by no means be looked upon exactly in the same light as if they had been performed at equal elevations in the atmosphere above the level of the sea. In the former case, the heating surface is raised into the higher regions, and cannot fail to produce a modification of circumstances, different from those which the simple problem supposes. As the existence, however, of an effect, and not its amount, is here required to be proved, the example will suffice.

It is a consequence which naturally and infallibly flows from that general alteration of temperature which does not affect the barometer at the level of of the sea; for as the expansion and contraction do not alter the total weight of the aërial column, it is clear that they must change the relative weights of its different sections.

§ 2. MEAN TEMPERATURE.

Amongst the data for meteorological computations, co-ordinate in importance with the mean pressure, is the mean temperature of the atmosphere at the level of the sea and at different heights above it. With regard to this point, our observations are both more numerous and more trustworthy than with regard

[illegible]

[illegible]

[illegible]

[illegible]

oceanic currents established by the relations of heat to matter in this physical state. The further equalization of climates is brought about by the rapid circulation of the air acting under the same influence.

The climate of the same place, notwithstanding perpetual, and apparently irregular, changes, possesses remarkable steadiness. As, for instance, the mean annual temperature of London is about 50°·4. In the year 1788, the cold was so unusually severe that the Thames was passable on the ice, and yet the mean temperature of that year was 50°·6, within a small fraction of a degree of the standard. In 1796, when, it is said, the greatest cold ever observed in London occurred, the mean annual temperature was 50°·1. In the severe winter of 1813-1814, when the Thames and other large rivers of England were completely frozen over, the mean temperature of the two years was 49°, being little more than a degree below the standard. And in the year 1808, when the summer was so hot that the temperature in London was as high as 93°·5, the mean temperature of the year was 50°·5.

It is probable that if the whole surface of the earth were uniform, and presented the same relations to radiant heat, its mean temperature at every point might have been obtained by multiplying its equatorial temperature into the cosine of the latitude; or in other words, that it would have been in proportion to the radius of its parallel of latitude. The following Table exhibits the near accordance of actual observation, in many places, with this hypothesis, notwithstanding the unequal action of disturbing causes.

It was calculated upon the supposition of an equatorial mean temperature of 81°·50 Fahr. by a formula which we owe to Dr. Brewster, $T = 81·5 \cos. L.$

TABLE XLI. *Comparison of calculated with observed Mean Temperature, by Dr. Brewster's First Formula.*

	Latitude.		Observed Mean Temperature.	Mean Temperature calculated by Formula.	Difference.
	°	′	°	°	°
Equator - -	0	0	81·50	81·50	0·00
Columbo - -	6	58	79·50	80·90	1·40 +
Chandernagore	22	52	75·56	75·10	0·46 –
Cairo - - -	30	2	72·82	70·56	1·76 –
Funchal - -	32	37	68·54	68·62	0·08 +
Rome - - -	41	54	60·44	60·66	0·22 +
Montpellier -	43	36	59·36	59·	0·33 –
Bourdeaux -	44	50	56·48	57·82	1·34 +
Milan - - -	45	28	57·18	58·28	1·10 +
Nantes - -	47	13	54·68	55·35	0·67 +
St. Malo - -	48	39	54·14	53·85	0·29 –
Paris - - -	48	50	51·89	53·65	1·76 +
Brussels - -	50	50	51·80	51·47	0·33 –
Dunkirk - -	51	20	50·54	51·25	0·71 +
London - -	51	30	50·36	50·74	0·38 +
Bushey Heath	51	37¾	51·20	50·58	0·62 –
Kendal - -	54	17	46·02	47·58	1·56 +
New Malton -	54	10	48·28	47·53	0·75 –
Lyndon - -	54	34	48·90	49·37	0·47 +
Dublin - -	53	21	49·10	48·65	0·45 –
Copenhagen -	55	41	45·68	45·95	0·27 +
Edinburgh -	55	57	46·23	45·64	0·59 –
Carlscrona -	56	16	46·04	45·46	0·58 –
Fawside - -	56	58	44·30	44·26	0·04 –
Kinfauns - -	56	23½	46·20	45·12	1·08 –
Stockholm -	59	20	42·26	41·57	0·69 –
Upsal - - -	59	51	42·08	40·94	1·14 –
Abo - -	60	27	40·00	40·28	0·28 +
Umeo - -	63	50	33·08	35·96	2·88 +
Uleo -	65	30	33·26	34·38	1·11 +

The temperatures appropriate to the parallels of latitude upon this hypothesis have been inserted upon the maps at every 10°, as standards of comparison.

2. But the unequal distribution of land and sea in the polar regions producing great irregularities in the action of heat, causes great deviations from this general law, so that, according to the observations of Scoresby, the mean temperature of the Spitzbergen seas, in the latitude of 78°, amounts to 16°·99, while, according to the observations of Parry, the mean temperature of Lat. 74°·45 in the meridian of 110° W, is only 1°·33.

A general difference of mean temperature exists, in fact, between the parallels of latitude of the old and new world, which are best exhibited by tracing *isothermal* lines, or lines of *equal heat*, upon a map, as first suggested and executed by Humboldt. Such circles of equal temperature are delineated upon the accompanying map corrected to the latest observations. A slight inspection at once shows that the temperatures are not the same under the same parallels, and that by advancing 70° to the east or the west a sensible alteration in the mean heat of the atmosphere is found. It will also be obvious that the difference depends mainly upon the distribution and configuration of the land; and that places situated under the same latitudes in the interior of the continents of Europe and America, by no means differ so much from one another as from those which are within the verge of the Atlantic and Northern oceans.

It is the parallel extension of the two continents

in the northern hemisphere towards the pole, separated as they are by these waters from each other, and from the pole itself, which produces the effects of two poles of cold not coincident with the terrestrial pole. They must not, however, be regarded as centres of force influencing the temperatures of their repective meridians, but merely as the resultants of that distribution of heat which we have indicated. The curvature of the isothermal lines plainly indicates such an arrangement as first pointed out by Dr. Brewster, but their exact geographical position it would be difficult to determine with accuracy. That eminent philosopher upon this hypothesis has suggested a second formula by which the mean temperature of any point upon the surface of the globe at the level of the sea may be determined with considerable exactness from the limiting temperature of the equator and the poles. For this purpose he assumes, that the Asiatic pole of lowest temperature is situated about 80° N. Lat. and 95° E. Long., and to be of the temperature of $+1°$, and that the transatlantic pole is situated about 80° N. Lat. and 100° W. Long., and of the temperature of $-3°{\cdot}5$.

Then the Mean Temp. $=(81{\cdot}8° \text{ Sin. D})+1°$ for the Asiatic Meridian;

and $T=(86°{\cdot}3 \text{ Sin. D})-3°{\cdot}5$ for the Transatlantic Meridian;

In these equations, D is the distance from the nearest Isothermal pole.

The following Tables present the results of calculations founded upon this hypothesis compared with observation.

TABLE XLII. *Comparison of calculated with observed Mean Temperatures, by Dr. Brewster's Second Formula.*

ASIATIC MERIDIANS.

Names of Places.	Distance from the Asiatic Pole of cold.		Mean observed.	Calculated.	Difference.
	°	′	°	°	°
Enontekies -	20	39	31·03	29·85	– 1·18
Uleo - - -	23	16	33·08	33·31	+0·23
Umeo - - -	25	06	33·26	35·70	+2·44
St. Petersburg	27	11	38·84	38·37	–0·47
Stockholm - -	29	44	42·30	41·57	–0·73
Moscow - -	29	55	43·16	41·80	–1·36
Warsaw - -	36	06	48·56	49·20	+0·64
Astracan - -	37	25	49·08	50·70	+1·62
Vienna - -	40	37	51·76	54·25	+2·49
Pekin - - -	40	56	54·86	54·59	–0·27
Nangasaki -	48	57	60·80	62·69	+1·89
Seringapatam -	68	04	77·00	76·92	–0·08
Columbo - -	73	12	79·50	79·33	–0·17

TRANSATLANTIC MERIDIANS.

Names of Places.	Distance from the American Pole of cold.		Mean observed.	Calculated.	Difference.
	°	′	°	°	°
Melville Island	5	15	1·33	4·39	+3·06
Upernavick -	12	15	16·34	14·81	–1·53
Omenak - -	13	58	16·60	17·33	+0·42
Godhavn - -	17	08	22·04	21·92	–0·12
Godthaab - -	20	19	26·07	26·46	+0·39
Fort Churchill	20	58	25·34	27·38	+2·04
Julianæshab -	24	25	30·33	32·17	+1·84
Eyafiord - -	24	08	32 16	31·78	–0 38
Nain - - -	25	16	30·03	33·34	+3·31
Okkak - - -	24	47	31·00	32·68	+1·68
Quebec - -	34	44	41·90	45·67	+3·77
Cambridge - -	39	04	50·36	50·89	+0·53
New York - -	39	53	53·78	51·84	–1·94
Philadelphia -	41	08	53·42	53·27	–0·15
Williamsburg -	43	40	53·10	56·09	–2·01
Orotava - -	60	00	70·11	71·94	+1·13
Equator - - { W. L. 100° / E. Lon. 95° }	80	00	81·50	{ 81·50 / 81·56 }	0·00 / +0·06

The fact, however, of the increase of mean temperature of the atmosphere from the poles to the equator and its general limits, is all that we are at present concerned to establish.

3. We must next direct our attention to the law of the distribution of the mean temperature in the upper strata of the atmosphere. We owe to Dr. Dalton, as has been before stated, the discovery that the natural condition of the equilibrium of heat in a gaseous atmosphere is found when each particle of air in the same perpendicular column is possessed of the same quantity of heat; and consequently that such an equilibrium results when the temperature gradually diminishes in ascending. When the quantity of heat is limited the temperature is thus governed. Professor Leslie determined the law of the progression by delicate experiments, and expressed it by a simple formula of which we have made use in determining the conditions of our hypothetical atmosphere (p. 33). We must now endeavour to ascertain how nearly this law may agree with direct observations at different heights in the actual atmosphere; and we cannot anticipate that we shall find more than general agreement with the theory which we formed in tracing the progression of temperature upon the surface of the globe: for the causes of disturbances are numerous, and there is not the same opportunity as at the lower stations of correcting their fluctuations by the system of means.

The most unexceptionable observations for this purpose are those which were made by M. Gay Lussac in his celebrated aërostatic voyage. He attained the unprecedented height of 22,850 feet, and the tempe-

rature being 82° at starting, he found it to be 15° at this elevation, making a difference of 67°, or a fall of 1° for each 341 feet of ascent. Upon referring back to Table VII., it will be seen that we have brought out by Leslie's formula the temperature of an atmosphere of 80° at the surface, 12°·8 at an elevation of 20,000 feet, which is about 1° for each 300 feet of ascent. This will be deemed a near coincidence, when we take into consideration the circumstances under which the observations were made, and that in the rapid ascent of the balloon it must almost necessarily have happened that the thermometer had not time to take up the exact state due to the ascent of the barometer by which the height was measured. A Table of the successive observations at different heights is here subjoined, which will not only exhibit the principal fact upon which we are insisting, but also certain irregularities in the scale of temperature, upon the probable causes of which we have already speculated. The final result, as has been just stated, exhibits a fall of 1° for every 341 feet of ascent. Up to 10,000 feet, it is 1° for 367 feet; to 12,089 feet, 1° for 345 feet; to 18,387 feet, 1° for 367; to 20,001 feet, 1° for 377 feet. It will, however, be remarked that between 12,089 feet and 18,585 feet the regular gradation of temperature is broken, and hot strata appear to have been interposed between those of equivalent temperatures. Similar smaller irregularities also occur in still higher regions; but the general law is maintained, notwithstanding these indications of disturbing influences.

TABLE XLIII. *Results of the Observations of M. Gay Lussac upon Temperature and Pressure in his Aërostatic Voyage.*

Temperature.	Pressure.	Height in Feet.
	Inches.	
82°	30·126	0
55	21·190	9,929·8
52	20·247	11,274·6
47	19·559	12,089·
51	19·310	12,499·9
54	18·370	13,966·7
50	18·212	14,173·7
47	17·338	15,469·3
44	17·137	15,746·2
48	17·826	14,775·5
41	16·728	16,381·
40	16·196	17,251·8
37	15·688	18,069·2
33	15·358	18,585·1
34	16·303	13,498·3
26·5	14·633	19,783·2
29	14·550	20,001·0
32	15·425	18,387·3
26	14·448	20,119·3
19	13·145	22,545·5
15	12·944	22,850·8

Such a direct ascent in the free atmosphere must present us with results free from the interference of many disturbing causes which must necessarily affect those which have been obtained by the ascent of mountains; but as the latter are by far more numerous, their mean, from the balance of oscillations, may be expected to exhibit the general law with even more precision than the former. In the following Table are forty-two measurements made in circumstances of a very varied kind, and free from the suspicion of errors of any considerable magnitude.

Table XLIV. *Decrements of Temperature observed at different Altitudes in the Atmosphere.*

	Names of Places.		Altitude of the columns of air, in feet.	Temperature at the lowest Stations	Temperature at the upper Stations.	Height in feet for a decrement of 1° Fahr.
1	Gay Lussac's aërostatic ascent	Paris	22,896	82·	15·	341
2	Chimborazo	South Sea	19,287	77·5	29·1	396
3	Mont Blanc	Geneva at noon	14,350	82·9	26·8	255
4	Do.	at 2 o'clock	... ...	81·7	29·1	273
5	Peak of Teneriffe	Orotava (Cordier)	12,234	76·8	47·1	411
6	Mont Blanc	Chamouni, at noon	12,211	73·4	26·8	258
7	Do.	at 2 o'clock	... ...	77·0	29·1	255
8	Ætna	Catania (Saussure)	10,619	73·6	39·9	324
9	Mont Perdu	Tarbes	10,226	78·1	44·4	304
10	Giant's Neck	Geneva	10,039	76·8	40·1	273
11	Maladette	Tarbes (Cordier)	9,527	69·4	38·1	304
12	Pic du Midi	Tarbes July 26, 1809	8,572	81·5	52·9	298
13	Do.	Sept. 15, —	... ...	67·3	47·5	433
14	Do.	Sept. 4, 1803	... ...	72·5	46·6	329
15	Do.	Sept. 12, —	... ...	74·3	50·7	360
16	Do.	Sept. 23, —	.. ...	65·8	46·6	444
17	Do.	Sept. 27, —	... ...	66·4	39·2	315
18	Do.	Sept. 30, —	... ...	58·6	39·7	453
19	Giant's Neck	Chamouni	7,821	70·9	40·1	253
20	Mont Perdu	Barèges	7,060	77·0	44·4	216
21	Pic D'Eyre	Tarbes	7,043	70·3	51·8	378
22	Gunaxuoto	South Sea	6,837	77·5	70·3	949
23	Pic de Montagne	Tarbes	6,735	58·1	37·6	327
24	Pic de Bergons	Tarbes	5,975	66·2	56·3	594
25	Pic du Midi	Barèges Aug. 30, 1805	5,429	80·1	61·5	293
26	Do.	Sept. 15, —	.. ...	71·4	46·4	216
27	Do.	Aug. 15, 1809	... ...	70·3	46·8	231
28	Do.	Sept. 23, —	... ...	65·3	42·8	240
29	Do.	Oct. 19, —	... ...	60·6	36·5	223
30	Do.	Sept. 11, 1810	... ...	64·0	44·6	278
31	Do.	Sept. 22, —	... ...	66·0	42·4	229
32	Do.	Sept. 28, —	... ...	65·1	41·4	227
33	Puy de Dôme	Clermont June 25, 1806	3,497	70·3	57·9	280
34	Do.	Oct. 11, 1807, at noon	... ...	64·0	51·4	276
35	Do.	1 o'clock	... ...	65·5	53·1	280
36	Do.	June 29, 1808	... ...	76·6	59·4	202
37	Do.	Aug. 7, —	... ...	91·2	74·1	204
38	Mountain above Bagnères,	Tarbes	3,116	50·5	49·3	2,473
39	Bèdat de Bagnères	Tarbes	1,840	51·6	46·4	351
40	Pont du Berger	Clermont	1,614	32·5	26·8	280
41	The Barracks	Clermont	1,246	74·5	71·2	384
42	Prudelle	Clermont	941	82·9	77·0	158

The mean decrement resulting from the forty-two observations is 370·7 feet per degree: but leaving out the observations 22, 24, 38, and 42, in which disturbing causes appear to have prevailed to an extraordinary degree, and which deviate the most widely from the rest, the decrement is exactly 300 feet per degree. Thus far, then, we have the inferences of our hypothesis with regard to the distribution of pressure and temperature generally confirmed by the results of experience.

We must next inquire whether we can find any indications in nature of that grand system of compensating currents which we concluded to be the necessary consequence of such a state of things, and which must regulate all the other motions of the atmosphere, which are subordinate to it.

§ 3. CONSTANT WINDS.

With regard to the winds, we are unfortunately almost entirely destitute of those quantitative determinations of force and velocity which can alone render observations available to the purposes of accurate science. Indeed, till very lately, means were entirely deficient of measuring them with any precision; but accurate and self-registering anemometers have at length been contrived, and it is to be hoped that their introduction into regular observations will speedily supply the necessary data for important calculations.

All the most valuable information we possess of the great aërial currents we owe to the art of navigation,—an accurate knowledge of the winds being of course of first-rate importance to the mariner. Much

practical knowledge upon the subject, it is to be feared, however, has been lost, from want of a systematic registration and discussion of the facts.

1. Soon after the discovery of the New World, it was ascertained that on both sides of the equator, as far as the tropics, there is a tendency in the wind upon the broad ocean to blow from the east towards the west; and this constant current received the name of the *trade wind*, from the great facility which it offered to the traffic which was carried on with the new continent. The voyages of Cook and Dampier, of Horsburgh and other eminent navigators, gradually accumulated vast stores of information upon this most important subject, from which, as well as from his own extensive observations, Capt. B. Hall has drawn a connected sketch of the phenomena, of the utmost value both to theory and practice*.

The trade winds in the Atlantic and Pacific Oceans extend to about twenty-eight degrees of latitude on each side of the equator; but their direction is by no means uniform. On the northern verge of this space the wind generally blows directly from the east, but gradually draws round from E. to N.E., and finally to N.N.E., or even N. The southern limit to the north-east trade wind varies with the season of the year, reaching at one time to within three or four degrees of north latitude, and at other times not approaching it nearer than ten or twelve degrees. This irregularity, we may at once observe, is owing to the motion

* See Capt. B. Hall's Letter, subjoined.

of the sun and the consequent shifting of the parallel of greatest heat. The north-east trade, however, never crosses the equator to enter the southern latitudes. We cannot now enter upon the detailed consequences of these variations of the seasons; but must be content to consider the phenomena, as represented upon the map, in their mean state, or at the time when the sun is upon the equator. Between the northern and southern trade winds a considerable space intervenes, which is subject to perpetual calms and shiftings of the wind to every quarter, which is known to seamen by the name of "the variables." This range varies from 150 to 550 miles in width. The south-east trade, which sets in after crossing the "variables," blows at first nearly from the south, gradually drawing round to S.E., then to the E.S.E., and at last to E., at the southern limit of the trade winds, properly so called. In the latitudes beyond the trades, westerly winds prevail in both hemispheres, but most regularly in the southern, on account of more extensive disturbing influences in the northern, to which we shall hereafter direct our attention. The course of these phenomena, derived from experience, corresponds exactly with the hypothesis which we proposed, even in minute consequences, which have not yet been pointed out.

When the comparatively slow-moving air of the temperate zone, caused by the rotatory motion of the earth to the east, first comes into contact with the quick-moving, or tropical belt of the globe, the difference of their velocities is great, compared with its

direct motion towards the equator; and consequently the wind blows, at the extreme edge of the trades, nearly from the east point. As this cool air, however, is drawn nearer to the equator, and comes successively in contact with parallels of latitude moving faster and faster, this constant action of the earth's rapid easterly motion gradually imparts to it the rotatory motion due to the equatorial regions, which it has now reached. Thus the trade wind gradually loses the eastern character which it had on first quitting the temperate for the tropical region, in consequence of its acquiring more and more that of the rotatory motion of the earth due to the equatorial regions it has reached. While the easterly direction of the trades becomes thus destroyed, their meridional motion remains nearly constant, and becomes more and more apparent; and there is left only this motion towards the equator, which is found invariably to characterize the equatorial limits of both trade winds. This velocity is also at length checked by the friction on the surface of the earth, and by the meeting of the opposite currents.

2. With regard to the counter-currents in the upper regions of the atmosphere, opportunities of making experiments are necessarily very rare; and observation has been less directed to them than to the currents which we have been describing, on account of their less obvious connexion with practical purposes. It has, however, been remarked, that in the regions of the trade winds the higher clouds are very seldom, if ever, observed to go in the same direction as the wind

below. In general they are seen to move nearly in a contrary direction; and those who have ascended the Peak of Teneriffe have constantly found the wind blowing on the summit from the south-west, in the opposite direction to the trade wind below.

Upon the summit of Mouna Kea, in Hawaii, one of the Sandwich Islands, the height of which is estimated at 18,000 feet, Mr. Goodrich found, in April, a cold blustering wind from the south-west, at the time when the regular trade wind, from north-east, was blowing at its base. The traveller Bruce noticed a similar fact in Abyssinia.

An eruption of a volcano in the island of St. Vincent, in the year 1812, afforded evidence of this opposition of currents of a very striking nature, and placed the fact beyond dispute. The island of Barbadoes is situated considerably to the east of St. Vincent, and, between the two, the trade wind continually blows, and with such force, that it is with considerable difficulty, and only by making a very long circuit, that a ship can sail from the latter to the former. Notwithstanding this, during the eruption at St. Vincent, dense clouds were formed at a great height in the atmosphere above Barbadoes, and a vast profusion of ashes fell upon the island. This apparent transportation of matter against the wind caused the utmost astonishment among the inhabitants. A similar phenomenon was observed on the great eruption of the volcano of Cosiguina, on the shores of the Pacific, in Guatemala, in January, 1835; some of the volcanic ashes fell upon the island of Jamaica, at the distance of 800

miles in a direct line east from the volcano. At the same time others were carried in the contrary direction westward, and fell upon H.M. ship *Conway*, in the Pacific, more than 1,200 miles distant. The certainty of these facts cannot but be considered as of the utmost interest to the science of Meteorology.

Now it must be observed that it is within the limits of these trade winds that the atmospheric pressure is most constant and the barometer fluctuates to a very small amount,—rising and falling at the same same hours of the day with the regularity of a clock. This fact, and the constant mean height of the barometer in the same latitudes, prove another important inference from our hypothesis, namely, that the quantity of air which passes below from the poles to the equator must be exactly balanced by an equal quantity flowing above in the opposite direction.

3. The strict limits of the trade winds are amongst the most remarkable of their phenomena, and can only be accounted for by the air of the upper current being cooled in its course, and from its momentum and increased density descending upon the extra-tropical regions, displacing the lower current, and encountering a part of the globe going to the eastward at a much slower rate than itself. This equatorial air frequently comes, with scarcely any diminution of its velocity from friction, in contact with a part of the earth moving more than 100 miles more slowly to the eastward than itself; consequently furious westerly gales are constantly encountered as far as Madeira on the one side, and the Cape of Good Hope on the other, which

lie just beyond the north-east and south-east trade winds in the opposite hemispheres. The ascent of the slower moving particles of the lower stratum must at the same time check the rotatory velocity of the current towards the poles, into which they are carried; so that when in the process of vertical circulation they in turn become cooled, they descend with less momentum to the surface of the earth. The descent of the air in this state of rapid rotation is determined, in different latitudes, by various capricious causes; hence the zones between the tropics and the polar circles become the arenas of the perpetual struggles of opposing forces, the principal directions of which are evidenced by the alternate prevalence of winds from the south-west and north-east.

Some measure of the proportion of westerly to easterly winds in the northern extra-tropical latitudes is afforded by the number of days required by the sailing packets from Liverpool to New York to make their passage outwards and homewards, upon an average of six years. The passage from east to west occupies forty days, while the return from west to east requires only twenty-three.

The fundamental fact must never be lost sight of, that these easterly and westerly winds, which thus occupy definite parallels upon the surface of the globe, are secondary phenomena, and depend for their existence upon that meridional pressure of the polar atmosphere upon the equatorial in its lower stratum, and of the equatorial upon the polar in its upper stratum, which we have assumed as the basis of our reasoning.

4. The primary direction of the lower current is often masked from observation by such secondary effects and local disturbances which do not similarly affect the upper current; but a virtual translation of its great mass towards the equator must exist, as a necessary condition of the other regular movements.

In our northern latitudes, particularly, we are so much under the influence of conflicting forces, that we have difficulty in recognising in our variable winds the compensating agents of the high equatorial current; but it is certain that this conflict is confined to a very narrow stratum of the atmosphere, resting immediately upon the surface of the earth. Mr. Green and Mr. Monck Mason are both of opinion, from their aëronautic experience, that "in this country, whatever may be the direction of the wind below, within 10,000 feet above the surface of the earth, the direction of the wind is invariably from some point between the north and west." There can be little doubt that above this again flows the great counter-current from the equator.

We are too apt, perhaps, to form our notions of the great atmospheric currents from the character of the winds to which we are exposed upon the surface of the earth; but a little consideration and observation will enable us to correct this prejudice. The lower strata of the inferior currents are perpetually opposed by fixed obstacles—mountains, hills, rocks, forests, and the works even of man—against which they expend most of their force, and by which they

which flows on undisturbed by the most furious storms and the mighty billows which oscillate above.

§ 4. AQUEOUS VAPOUR.

If there be one point of more interest and importance than another in Meteorology, it is certainly the perpetually varying state of the great ocean of aqueous vapour which permeates the gaseous atmosphere: but it has hitherto been sadly neglected by observers, who even in the few observations which have been regularly made, from idleness or prejudice, have persevered in the use of imperfect instruments, when more perfect ones have been at command. We can nowhere find mean results for every part of the globe comparable with those which we possess for temperature, by which to test our theoretical conclusions; but still experience, as far as it has been recorded, confirms that general distribution of the vapour which seemed legitimately to follow from our hypothesis.

1. There cannot be a doubt that on the surface of the earth at the level of the sea, the average elastic force and constituent temperature of the vapour decreases with the mean temperature, and in the immediate neighbourhood of the sea, the dew-point may be reckoned as two or three degrees below it. In the following Table will be found the results of the most authentic observations which have been collected upon the subject.

TABLE (XLV.) *of the Mean Dew-point and Force of Vapour in different Latitudes on the level of the sea.*

Points of Observation.	Observers.	Dew-point.	Force.
			Inches, Mercury.
Atlantic—between Lat. 24° 25′ S. and 27° 30′ N. -	Hon. Capt. Spencer	average 72°	0·773
Do. - Gulf of Guinea -	Major Sabine	from 74° to 80°	0·911
Do. - St. Thomas -	Do.	71 to 74	0·773
Indian Ocean—Bombay - -	Capt. Sykes	73 to 76	0·853
Atlantic - Madeira - - -	Dr. Heineker	59·4	0·497
Do. - London - - -	Mr. Daniell	44·5	0·290
Polar Sea—between 71° 20′ and 73° 48′ - - - - -	Capt. Parry	27·6	0·157

M. Neuber, of Apenrade, in Denmark, made every two hours for a year, observations of Daniell's hygrometer, from 7 A.M. to 11 P.M. The mean of all these observations gives 0·346 as the tension of the vapour, and the means of the several hours as in the following Table.

TABLE (XLVI.) *of mean hourly Variations of Vapour at Apenrade.*

Time.	Inches Mercury.	Time.	Inches. Mercury.
7 A.M. -	0·319	3 P.M. -	0·372
9 „ -	0·343	5 „ -	0·358
11 „ -	0·363	7 „ -	0·332
12 Noon -	0·370	9 „ -	0·321
1 P.M. -	0·374	11 „ -	0·391

With regard to the last result in Table XLV. it is the mean of observations made only in the months of August and September which is recorded. and this must be greatly above the average of the year. During the winter, at Port Bowen, attempts were

made to detect vapour in the atmosphere, but no dew-point could be obtained with a temperature of $-50°$.

2. Observations upon heights, for the purpose of ascertaining the law of the decrease in the elasticity of the vapour due to the elevation, are still more deficient; and yet we can collect evidence enough to prove the correctness of the inference we have drawn from the hypothesis, namely, that the force does not decrease gradually as we ascend, in proportion to the gradual decrease of the temperature and density of the air; but the dew-point remains stationary up to great heights, and then suddenly falls to a large amount.

Saussure remarked that his hygrometer, near the surface of the earth, often proved the air to be removed 30 or 40 degrees from extreme saturation when the presence of clouds in the upper sky demonstrated the perfect humidity of that region. That eminent philosopher often observed this phenomenon when he ascended a mountain whose summit was enveloped in a cloud. On the other hand, he as frequently found, that when mists covered the plains and a bright sun gilded the summit of the mountain, the limit of extreme humidity was below, and air, far removed from saturation, above. Bands of clouds he sometimes found to swim between masses of air less humid than themselves.

The first direct experiments to which I shall refer, as bearing upon this point, are those of Mr. Green, the aëronaut. An account of this gentleman's ascent in a balloon, from Portsea, on the 6th of September, 1821, is given in the 12th volume of the *Journal of*

the Royal Institution (p. 114). Amongst other instruments of research, he took up with him a dew-point hygrometer. He unfortunately omitted to take the point of deposition, before he commenced his ascent; but the omission is of less consequence as I happened to make an observation at the time, at no very great distance from the spot. At an elevation of about 9890 feet, he found the dew-point at 64°, exactly the same as I ascertained it to be at the surface of the earth. At 11,060 feet it had fallen to 32°, making a difference of 32 degrees in little more than 1100 feet. Here, then, we have presumptive evidence of an immense bed of vapour rising in its circumambient medium, unaffected by decrease of density or temperature till checked by its point of precipitation; and of an incumbent bed of not much more than one-third the density, regulated, no doubt, as the last, by its own point of deposition in loftier regions.

Colonel Sabine, by his experiments upon mountains in tropical climates, has established the same fact in the most unexceptionable manner. At Sierra Leone, he ascertained that the dew-point of the vapour, at the level of the sea, was 70°; and that it was the same at the same hour upon the summit of the Sugar-loaf Mountain, 2520 feet above. At the Island of Ascension, the barometer, 17 feet above the level of the sea, stood at 30·165 inches—temperature of air 83°, and the dew-point 68°. On the summit of the mountain the barometer fell to 27·950 inches, and the temperature of the air to 70°, while the dew-point only declined to 66°·5; so that in a height of 2220

feet, the temperature of the air fell 13°, and the constituent temperature of the vapour 1°·5.

At Trinidad, the temperature of the air at the level of the sea was 82°, and the dew-point 77°; 1060 feet above, they were both 76°·5, and precipitation was going on.

At Jamaica, by the sea-side, the temperature of the air was 80°, and the point of deposition 73°; while on the mountains, at a height of 4080 feet, they were both 68°·5. At a station not 500 feet higher, by experiment twice repeated, the point of deposition was found to be 49°, and the temperature of the air 65°.

Colonel Sabine's experiments furnish also some evidence of that slight diminution of density in the upper parts of the beds of vapour which would arise from the decrease of their own pressure, and which had been anticipated in the second part of this Essay. In the experiments at Jamaica, the dew-point fell about 4°·5 in 4080 feet. In Table XXIII. it will be seen that this diminution had been calculated to be 3°·5 in 5000 feet for an atmosphere of much less density.

From the following interesting account of the ascent of the Peak of Teneriffe communicated by Captain Basil Hall, we obtain strong confirmation of the opinion that part of the vapour of the atmosphere is arranged in beds, each of which varies little in its own density but very greatly from the others.

"On the 24th of August we left Oratava to ascend the Peak. The day was the worst possible for our purpose, as it rained hard, and was so very foggy, that

we could not see the Peak, or indeed any object beyond one hundred yards distant.

"After riding slowly up a rugged path for four hours, it became extremely cold, and as the rain never ceased for an instant, we were by this time drenched to the skin, and looked with no very agreeable feelings to the prospect of passing the night in wet clothes. At length the night began to close in, and the guides talked of the improbability of reaching the English station before night. It was still raining hard; but we dismounted and took our dinner as cheerfully as possible, and hoping for clearer weather the next day. On remounting we soon discovered that the road was no longer so steep as it had been heretofore, and the surface was comparatively smooth; we discovered, in short, that we had reached a sort of table land, along which we rode with ease. Presently we thought the fog less dense, and the drops of rain not so large, and the air less chilling. In about half an hour we got an occasional glimpse of the blue sky; and as we ascended, for our road, though comparatively level, was still upon the rise, these symptoms became more manifest. The moon was at the full, and her light now became distinct, and we could see the stars in the zenith. By this time we had reached the Llano de los Remenos, or Retamos Plain, which is many thousand feet above the sea; and we could distinctly see that during the day we had merely been in a cloud, above which having now ascended, the upper surface lay beneath us like a country covered with snow. It was evident on looking round, that no rain

had fallen on the pumice gravel over which we were travelling. The mules were much fatigued, and we got off to walk. In a few minutes our stockings and shoes were completely dried, and in less than half an hour all our clothes were thoroughly dried. The air was sharp and clear, like that of a cold frosty morning in England, and though the extreme dryness, and the consequent rapid evaporation, caused considerable cold, we were enabled by quick exercise to keep ourselves comfortable. I had various instruments with me, but no regular hygrometer; accident, however, furnished me with one sufficiently indicative of the dry state of the air. My gloves, which I kept on while mounted, were completely soaked with the rain; and I took them off during this walk, and, without considering what was likely to happen, rolled them up and carried them in my hand. When at the end of an hour, or somewhat less, we came to remount our mules, I found the gloves as thoroughly dried and shrivelled up as if they had been placed in an oven, and I could not manage to get them on again. During all the time we were at the Peak itself on the 26th, the sky was clear, the air quite dry, and we could distinguish, several thousand feet below us, the upper and level surface of the stratum of clouds through which we had passed the day before, and into which we again entered on going down, and found precisely in the same state as when we started."

In a highly interesting paper of Colonel Sykes upon the Meteorology of Dukhun, published in the *Philosophical Transactions* for 1835, we find some in-

teresting observations of the dew-point hygrometer bearing upon the same point. He was enabled, in the month of March, 1828, to establish comparisons derived from observations on consecutive days between Bombay, the top of the Ghàts, the Hill-fort of Loghur, and Poona. The stations varied, as will be seen, from the level of the sea to a height of 3381 feet, and were all within a moderate distance from one another.

TABLE XLVII. *Of the Elasticity of Vapour at different Heights.*

Time.	Places of Observation.	Sunrise.			9-10 A.M.			4-5 P.M.		
1828.		Temp. of air.	Dew-point.	Elasticity.	Temp. of air.	Dew-point.	Elasticity.	Temp. of air.	Dew-point.	Elasticity.
March 10	Bombay, level of sea - -	75	72	·775	81·5	71	·747	86	80	1·004
11	Kundullah, 1744 feet - -	72	36	·216	78	40	·250			
11	Karleh, 2015 feet - - -							87	40	·250
12	Hill-fort Loghur, 3381 feet	67	27	·153						
12	Karleh, 2015 feet - - -				84	34	·200	88	36	·216
13	Poona Hay Cottage, 1823 ft.				84	44	·290	89	35	·208
14	Ditto - - - - - - -	73	35	·208	84	37	·224	88	32	·185

Here we find an elevation of 1744 feet making a difference of only 3° in the temperature of the air, while the dew-point falls about 36°, indicating a sudden decline in the elasticity of the vapour from 0·773 in. to 0·206 in. At 260 feet higher the dew-point was found nearly the same as at the last station, but at 1300 feet higher it was found to have again declined 9°, and the elasticity of the vapour was only 0·153 inches.

3. The obvious general stratification of the clouds can be accounted for upon no other principle than that of the sudden attainment of the dew-point in the rise of different beds of vapour under the controul of the natural progression of temperature of the gaseous atmosphere in which they are confined. Had it not been for this provident adaptation of the two elastic fluids to each other, the atmosphere would necessarily have been at all times turbid throughout its depth with precipitating moisture; but, as it is, the clouds are confined to definite planes of precipitation. Nothing can be more interesting at times than to watch the indications of those natural hygrometers of the heights above us, and to observe the first precipitation of the moisture of the lower stratum of vapour carried by an almost instant evaporation into vapour of a lower tension, to still greater altitudes, again to be precipitated and again evaporated. When indeed the normal progression of temperature becomes necessarily disturbed by the process which we are contemplating, then the depths of air become turbid, the winds arise, and the rains descend, effect their beneficial purpose, and in effecting it restore the more permanent order due to the gaseous law.

Mr. Green has found that the isothermal planes of the atmosphere are parallel, or nearly so, to the earth's surface; so that the aëronaut knows generally, even though the earth may be intercepted by a cloud, when he is crossing a chain of hills, because the upper surface of the clouds generally follows in a great measure the configuration of the earth. "The

upper surface of the clouds, upon occasions when they overspread the earth at a moderate elevation, seems to accommodate itself to all the variations of form in the subjacent soil." Mr. Green has also observed that it is necessary, in order to experience an equal reduction of temperature, to ascend to a greater elevation when the earth is overspread with clouds than when the sky is cloudless.

§ 5. HORARY OSCILLATIONS OF THE BAROMETER.

Having seen how nearly the phenomena of the earth's atmosphere correspond in their great features with the normal state of the hypothetical atmosphere of permanent gases and vapour which we built up upon the acknowledged principles of hydrostatic and pneumatic science, we will now proceed to inquire into the causes of those fluctuations and disturbances which mask their regular order, and render it necessary to have recourse to the mean results of many observations spread over a long period of time for their detection. And first with regard to the pressure.

1. The barometer is perpetually oscillating on either side of its mean height, and indicating corresponding fluctuations of the atmospheric ocean. These changes are regular and of small amount between the tropics, but become apparently irregular and of greater range as we travel towards either pole: in the former situation they rarely amount to $\frac{1}{4}$ inch of the mercurial column, but in the latter they sometimes amount to $2\frac{1}{2}$ inch. In the former sitnation the mercurial column

rises and falls between certain limiting hours with all the regularity of a clock, and the phenomenon is so little affected by disturbing causes, that it scarcely requires to be eliminated from error by taking the mean of numerous observations.

In proceeding, however, towards either pole, the fluctuations of the barometer increase in extent, and appear to become more and more irregular; but upon taking the mean of many observations it is found that the regular horary oscillations are only masked by others which supervene and evidently arise from a different cause. These irregular oscillations neutralize one another in a long series of observations, and the mean of the limit hours is found to rise and fall in accordance with the equatorial results. The amount of the horary oscillations, however, decreases as we recede from the equatorial zone, and in the northern hemisphere have been ascertained to cease about the 64th degree of latitude, and to reappear to a small amount in still more northern regions at the same hours but in the opposite directions. The following Table exhibits the mean amount of the horary oscillations at different stations from the equator towards the north pole, and the corresponding mean monthly oscillations at the same place by which they are temporarily masked. As the amount of the former increases, that of the latter diminishes.

TABLE XLVIII. *Exhibiting the Mean Horary Oscillations and the Mean Monthly Oscillations of the Barometer between the Equator and North Pole.*

Stations.	Latitude.	Regular Oscillation.	Irregular Monthly Oscillation.
Lima -	10° 31′ S	0·108	
Caraccas -	22 35 N	0·085	
Cairo - -	30 2	0·060	0·326
Rome - -	44 54	0·038	0·675
Paris - -	48 50	0·021	0·931
Edinburgh -	55 55	0·008	1·040
St. Petersburgh -	59 56	0·005	1·151
Rosekop -	70	0·003	1·516
Port Bowen -	73 48	—0·010	1·362

The mean of all the observations from the equator to St. Petersburgh presents the following hours as the limits of the horary oscillation.

Minimum of night - -	4^h 5^m
Maximum of night - - -	10 11
Minimum of morning - -	3 45
Maximum of morning - - -	9 37

The geographical position has but little influence upon these limits, but the change of the seasons affects them more. In winter the barometer declines to 3 P.M., but in summer to 5, and generally speaking the turning points in winter are nearer to noon by two hours than in summer; and fall therefore later in the morning and sooner in the night.

2. Now it is clear that these horary changes must depend upon some cause as regular as their periodical recurrence, and they most probably have their origin in the daily revolution of the earth and the periodical

changes of temperature which are consequent upon it. We have not yet derived such a consequence from the constitution of our hypothetical atmosphere. We have made the supposition of an increase of ten degrees of temperature taking place along the whole extent of any given meridian, and a decrease of equal amount on the opposite line, all the meridians on either side being similarly affected in a regular gradation between the two, and we have shown what the effect would be upon the grand system of circulation of this approximation to the daily changes of temperature which occur in the atmosphere of the earth; but we have limited our supposition so that the increase and decrease of heat take place throughout the aërial columns *in so gradual a manner as not to affect the barometer at their bases*, or the regular progression of their equivalent temperatures. This can only arise from an exact and equal interchange of the heated and cooled particles in the vertical circulation between the two horizontal streams. A little consideration will serve to show that such a complete distribution of the air deriving its heat from below, although rapid, must require time for its completion. We have already (p. 17) explained the beautiful and complicated process of gyratory convection by which this diffusion of temperature is effected; a convection, be it remembered, not only of heat but of matter; the former being dependent upon the latter. If it were instantaneous, the equivalents of temperature would at once be established from below upwards through the perpendicular section of both the great currents; but

inasmuch as it requires time for its propagation, the lower current, which is in contact with the heated surface, is first affected, its elasticity tends to rise, and the ascensional force of its particles is unduly increased by the rising temperature of the day. The velocity of the ascending currents, which are established, particularly in the intertropical regions, is increased, and the descending cool particles which prevail in the polar regions, are checked. The supply of the lower current is proportionately cut off, and it is retarded in its horizontal course to the equator. The upper current meanwhile flows on with its acquired momentum towards the poles, and a portion of the aërial fluid is thus drawn uncompensated from the equatorial regions and heaped upon the polar. The barometer consequently falls in the former situation and rises in the latter; and indicates a regular progression between the two and a neutral position where the exact balance is maintained. The maxima of these effects are found to occur about one hour and a half, or two hours, after the earth has acquired its greatest temperature.

By this time some of the momentum of the upper current is expended, and the accumulation at the poles begins to react by its compression *with* the lower current and *against* the upper,—urging the former forward and checking the latter. It is the lower current which now advances with a velocity greater than is due to an exact balance of the two, and carried forward in its turn by its acquired momentum, it draws the atmosphere from the poles and

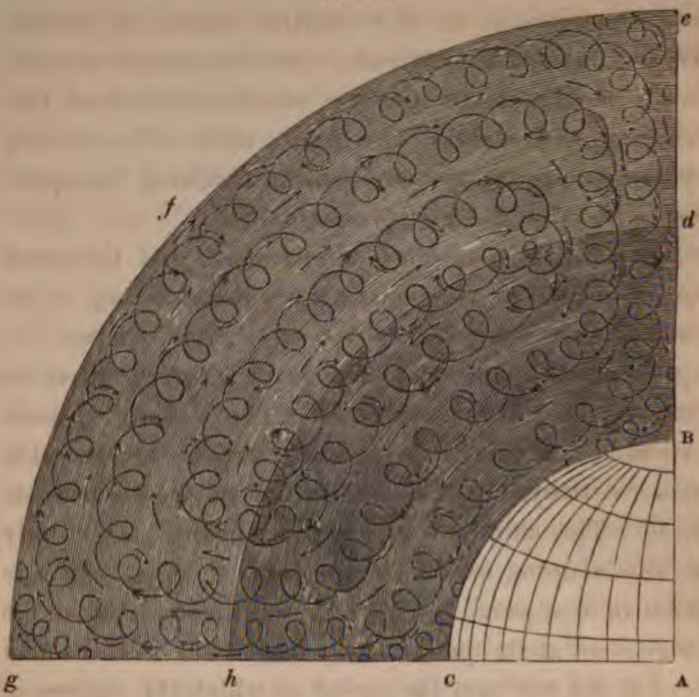
accumulates it at the equator,—the same balance being maintained at the neutral station as before. While this action proceeds, the temperature returns to its medium state, and the maximum effect of this revulsion occurs about two hours after. The cooling process assists at the same time in checking the upper current by diminishing its elastic force.

A reaction once more takes place, and the accumulated fluid of the equatorial regions, acting by its compression against the lower current, urges the upper current forward. The latter acquires momentum as the former loses it. The cooling process proceeds, and the balance of the vertical circulation is again destroyed by the diminution of the ascensional force. The supply of the upper current, particularly at the equator, is diminished, and flowing past the point of equipoise, it once more accumulates in undue proportion at the poles. The maximum of this effect occurs not far from the period at which the surface of the earth is the furthest removed from its mean state of temperature, in the opposite extreme to that which we before considered.

3. Two or three rude diagrams may perhaps assist the conception of these complicated phenomena, although the necessary want of all proportion between the spaces taken to represent the surface of the earth and the strata of the atmosphere renders the representations in this point of view absurd.

In fig. 10, let A B C represent a quarter of the hemisphere, and *d e f g h* a section of the atmosphere resting upon it. The atmosphere is divided into two

Fig. 10.



antagonist strata; namely, B *d*, flowing generally from the pole upon the earth's surface towards *h* C and the equator—and *g h* above returning from the equator to *e d* and the pole. This diagram is intended to recall to mind the action and reaction of the permanently heated and rare atmosphere of the equatorial, and the permanently cold dense air of the polar regions, combined with the periodical heating and cooling processes by which their inequalities of temperature are maintained. The united action of the differently-directed forces impresses upon the particles of the air, considered singly, a cycloidal motion; and they advance

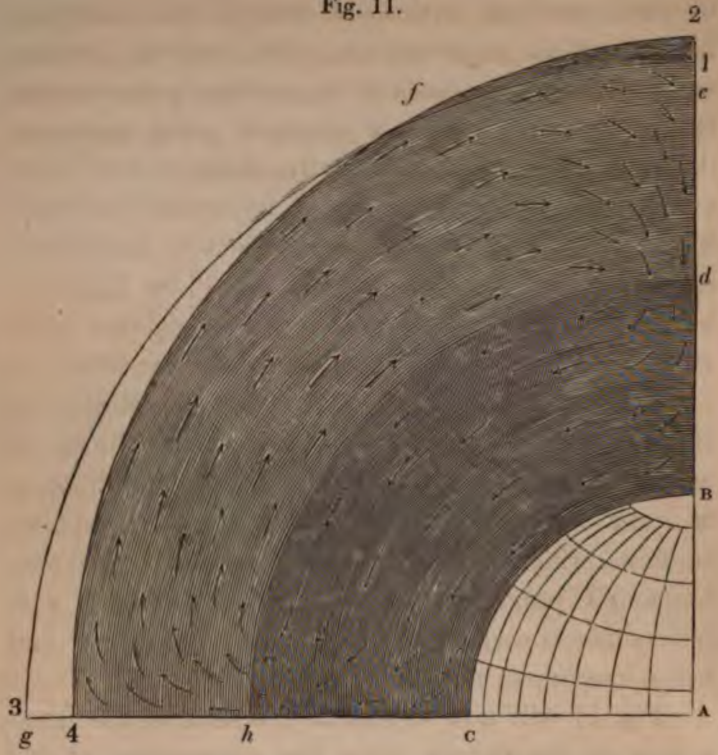
in their resulting horizontal courses with the same kind of rolling progress as a point upon the circumference of a carriage-wheel in motion advances upon the road. The curvature of their paths, however, differs of course with the relative differences of their ascensional, descensional, and horizontal motions. The general balance of these motions is here alone suggested: and such an equipoise would be indicated by the equal height of the barometric column upon the surface of the earth along the whole meridian.

The increasing heat of the day communicated to the air from the surface of the earth, along the whole extent of the lower current from C *h* to B *d*, imparts to it an increasing ascensional movement and an elastic force, which opposes its momentum and checks its horizontal progress. The upper current *g h*, *e d*, meanwhile is carried forward by its momentum, and heaps itself upon the polar regions.

Fig. 11 will now represent the state of the atmosphere at the instant when the momentum of the upper current is expended. 3, 4 indicates the deficiency of the equatorial extremity of the meridian, which decreases gradually to the neutral point *f*; and the space between 1, 2, indicates the accumulation at the polar extremity, which increases gradually from the same neutral point *f*. This simultaneous deficiency and accumulation is indicated by the proportionate fall and rise of the barometer along the same meridian.

This state of things being attained, and the momentum of the upper current which occasioned it being expended, the polar accumulation will commence its

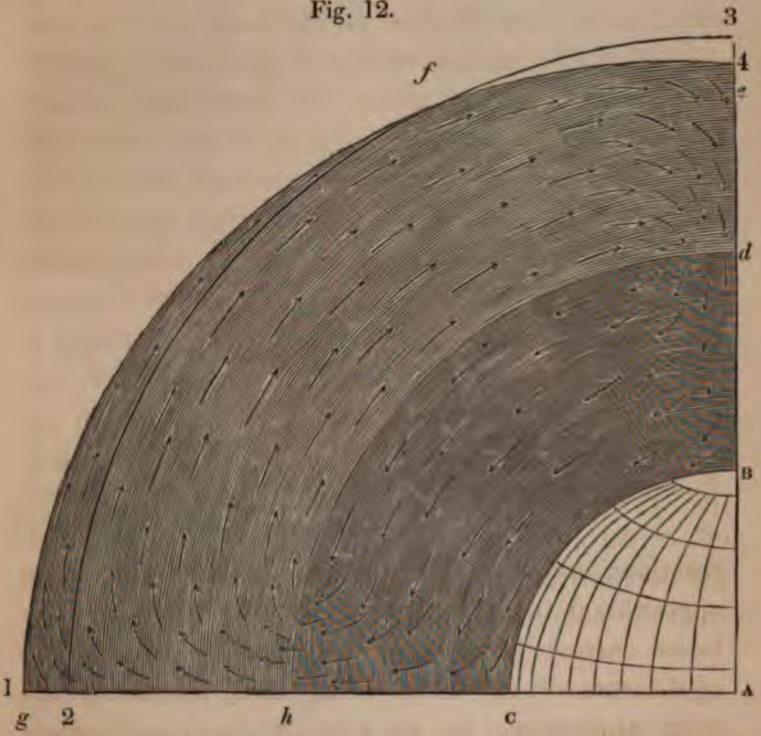
Fig. 11.



reaction; and it is clear that its pressure will act in opposition to the current *d e*, *h g*, whilst it will urge the lower current B *d*, C *h* forward upon its course. The momentum of the latter being thus increased, the polar atmosphere in its turn is disproportionately impelled towards the equator; and fig. 12 now represents the state of the atmosphere when the lower current has returned to its mean condition. 1, 2 represents the equatorial accumulation decreasing to the neutral point *f*, and 3, 4 the corresponding polar deficiency increasing from the same point.

It is now easy to perceive that the increased pressure at the equator will react upon the two currents in a direction opposite to that of the polar accumulation, checking the lower current *h* C, *d* B, but urging the upper *g h*, *e d* forward on its course.

Fig. 12.



This oscillating movement of the atmosphere may be likened in some respects to the vibrations of a pendulum or of the balance of a chronometer, the spring which keeps it in motion being the elastic force of heat reacting upon gravity. Or a conception of the course of the phenomena may be formed as of the fluc-

tuations of a great aërial wave oscillating upon the point *f*, in the direction of the meridian, the momentum of which is maintained by the alternate synchronous expansions and contractions of the lower current, generated by the daily fluctuations of the earth's temperature.

4. It might perhaps be supposed that as these oscillations are held to affect all the meridians in succession, in such a manner as that upon the same parallel of latitude there must always be two *maxima* co-existing with two *minima* of pressure, equidistant from each other, and apparently travelling round them all in succession, a lateral compensation would take place; but a little consideration will show that this would not be the case. An impulse given to a fluid already in motion would be propagated in the direction of that motion with much greater readiness than in any other,—as we find that the concussion from the detonation of a cannon is felt most in the direction of the wind. Moreover the interfering cause, the change of the daily temperature, is meridional in its action,—the maxima and minima extending at the same hours from the pole to the equator.

§ 6. IRREGULAR OSCILLATIONS OF THE BAROMETER.

It is clear that we must seek for the origin of the greater extra-tropical oscillations of the barometer in a different cause; for changes of temperature, arising from the regular processes of heating and cooling, in the alternations of day and night, and the vertical circulation dependent upon them, are insufficient for their explanation. We shall find it, as our hypothesis

suggests, in the irregular convection of heat produced by the formation and condensation of aqueous vapour.

The great characteristics of the tropical regions, (or rather of the tropical oceans, which are so extensive compared with the land, as necessarily to stamp the character of the climate,) are constancy of temperature and freedom from aqueous precipitation. Within these limits the perturbations of the atmosphere, to which we now refer, are almost unknown. The vapour, at its maximum of tension, as we have seen, passes north and south, and is scarcely liable to precipitation till it reaches the extra-tropical regions, and here the disturbance commences.

If we refer to the meteorological observations of Europe, in which quarter of the globe registers have been most constantly and carefully kept, we shall find that from the shores of the Mediterranean Sea to those of the Northern Ocean, the oscillations increase in range, and indicate an increase of intensity in the disturbing cause. It will also be found that barometers situated upon or nearly upon the same meridian, rise and fall together through an extent of 30° of latitude,—a coincidence which is perfectly consistent with our hypothesis of alternate checks and accelerations given to the grand system of currents, whose general direction is that of the meridians. It is clear that any irregularity in their flow would most readily be propagated in the direction of their course.

That the cause which we have assumed of these major oscillations is a "*vera causa*," and that the normal progression of temperature due to different

N 2

heights of the atmosphere is partially changed by disturbing causes, is proved by abundant observations. Aërostatic voyages, during which the thermometer has been consulted with care, prove that warm strata are often interposed between cold, and cold between warm; and the occasional ascents of lofty mountains afford numerous instances in which the temperature of the atmosphere has not followed the progression due to the density. This will at once appear, from the Tables which have already been given of the temperatures observed by M. Gay Lussac during his ascent, and of those of the ascent of the same mountain at different periods of the year. The contemporaneous registers, moreover, kept at Geneva and on the summit of St. Bernard, and which are published every month in the *Bibliothèque Universelle*, place the fact beyond dispute. The difference of temperature between these two stations is perpetually varying; and although the changes oscillate round the temperature due to the height, the general law of the decrease for the density is only to be derived from a mean of observations.

Of the influence of condensing vapour in producing these irregularities of temperature, we have direct evidence in the following observation of M. de Luc:

"Pendant que je réfléchissois sur l'apparition subite des nuages, je découvris un petit amas de vapeurs, du côté du nord, à 3 ou 400 pieds au-dessous de moi: Je le considérois avec attention, et je remarquois d'abord que son volume augmentoit sensiblement, sans qu'il me fût possible d'apercevoir d'où lui venoient ses

accroissements. Je vis ensuite qu'au lieu de s'abaisser à mesure qu'il grossissoit, et qu'il paroissoit même devenir plus dense, il s'élevoit au contraire. Le vent le poussoit vers moi. Il m'atteignit enfin, et m'environna tellement que je ne vis plus ni le ciel ni la plaine. Je pensai au même instant, à observer mon thermomètre, qui étoit suspendu en plein air, éxposé au soleil et que j'avois vu auparavant à + $4\frac{2}{3}$ (42° Fah.). Je présumois que l'action du soleil étant interceptée par ce nuage mon thermomètre devoit baisser et je fus très surpris de le voir au contraire à + $5\frac{1}{2}$ (45° Fah.). Le nuage, qui continuoit à monter obliquement vers le sud, abandonna bientôt le lieu où j'étois, le soleil reparut mais, malgré son action, le thermomètre rédéscendit*."

The subject of the oscillations of the barometer will hereafter be discussed at greater length than is consistent with our present purpose.

§ 7. PERIODICAL WINDS.

Amongst the secondary causes which disturb the course of that grand system of compensating currents, which must arise in an atmosphere surrounding a globe decreasing in its temperature in a regular progression from its equator to its poles, and rapidly rotating upon its axis, must of course be reckoned those inequalities of pressure which are measured by the oscillations of the barometer at distant places. In the equatorial zone of the earth and the imme-

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* De Luc, tom. iii. p. 251.

diately adjoining parallels of latitude where these oscillations are inconsiderable, we identify these currents with the trade winds with perfect precision, in all situations at a distance from the land; but, in the influence of land upon the phenomena, we find another disturbing cause, which we must proceed to consider.

1. The deep ocean is but little affected by sudden changes of temperature, such as those which occur from the succession of day and night; and it follows even but slowly the alternating temperatures of the seasons. Such changes are equalised over large tracts, by processes peculiar to its constitution as a liquid. Not so the land, which becomes rapidly but superficially heated by the action of the sun, and as rapidly parts with its heat in the absence of that luminary. Thus the great continents of the globe act as heaters and coolers of unequal and varying intensities upon the atmosphere, and modify the order of effects, which would flow from the mean temperature of the different latitudes, and from which the temperature of the water does not greatly deviate.

Hence the phenomena of the land and sea breezes which alternate with such regularity and are so refreshing upon the coasts of hot climates. The land becomes much more heated by the action of the sun's rays than the adjacent water; and the incumbent atmosphere is proportionally rarefied: during the day, therefore, the denser air of the ocean rushes to displace that of the land. At night, on the contrary, the deep water cools much more slowly than the land, and the reverse action takes place. The unbiassed direc-

tion of these breezes is therefore perpendicular to the coasts; but if the air be previously in motion from any different cause, the direction of the two combined will be the resultant of their respective forces. At the bottom of deep gulphs sea breezes are scarcely to be observed, and at the heads of promontories land winds alone prevail.

The trade winds, even, in the neighbourhood of the western coasts of the large continents, in their course have their direction changed by the same cause. Those parts of Africa and America which lie between the tropics, become intensely heated by the action of a vertical sun: the columns of the atmosphere, which rest upon them, must therefore be highly rarefied, and the more temperate air of the surrounding seas will press upon them. This influence is so decided as to overcome the tendency of the east wind; and on the western coasts of both continents a wind from the west prevails.

2. Of the same nature are the *monsoons* of the Indian seas and other periodical winds. They are occasioned by a particular distribution of land and water, acted upon by the periodical changes of the sun's declination. While the sun is vertical to the places where they occur, the land becomes heated, and the air expanded, and the wind flows toward the coasts. As the sun retires towards the opposite point of its course, the land cools faster than the surrounding seas, and the course of the winds is reversed. The simplest way of regarding the sun's motion in declination, as affecting the temperature of the various latitudes is,

to suppose a motion of the whole system; by which the line of greatest heat, and the two points of greatest cold, maintaining their relative distances, vibrate on either side of the earth's equator and poles.

In January the temperature of South Africa is at its *maximum*, while that of Asia is at its *minimum*. The part of the Indian Ocean north of the equator is hotter than the neighbouring continent, but not so hot as the southern part of the same ocean in an equal degree of south latitude. In both hemispheres, therefore, winds from the east are established towards the heated points. From October to April the south-east trade prevails in the southern hemisphere; and the north-east trade in the opposite; but the latter receives the name of the north-east monsoon: between the two exists a region of calms. When the sun advances to the north the temperature of the continent and of the sea approach to equality, and consequently about the vernal equinox variable winds alternate with calms and hurricanes in the northern hemisphere. In the southern hemisphere, on the contrary, the south-east monsoon reigns throughout the year. As the northern declination of the sun increases, the temperature of the Asiatic continent augments, while that of New Holland and South Africa declines. This difference of temperature is greatest in July and August, and during that time the wind blows constantly from the sea upon the northern coasts of the Indian Ocean. This movement, combined with the more rapid movement of the lower latitudes of the globe from which the air is drawn, gives to the mass a

south-west direction; and the south-west monsoon is thus established from April to October. Thus while in the southern hemisphere the south-east trade wind reigns throughout the year, to the north of the equator a north-east monsoon is established in the winter and a south-west monsoon in summer.

3. Bearing this general principle in mind, as well as that air in all cases in its passage from the equator, whether as a superior or inferior current, must bear with it the excess of its rotatory motion; those who apply themselves to the study of the phenomena of different localities will find no difficulty in explaining the course of the periodical winds which may prevail.

Although we have referred to these instances as apparent exceptions to the general consequences which we have drawn from our hypothesis, yet it will be found in this as in other cases, that "the exceptions prove the rule," for they afford us in every instance evidence of that rushing in of the dense surrounding air to supply the place of columns rarefied by heat which we have assumed as the main spring of the principal atmospheric movements. Local circulations of a subordinate kind and minor systems of compensation are thus produced which may affect, without reversing, the grand equatorial current which must necessarily flow from the equator to the poles, above the reach, probably, of those disturbing influences which agitate its great antagonist below.

It may now be understood, that it is the intermixture of land and water, joined with other disturbing causes, which prevents the extra-tropical western

winds from being as regular in their course as the tropical trade winds, and a slight inspection of the chart will demonstrate, that the northern hemisphere, including the great continents of Europe, Asia, and North America, must be more under this influence than the southern, which is comparatively free from such effects.

§ 8. VARIABLE WINDS.

The influence of the earth's rotation may, however, be traced even in the complicated relations of the winds of the temperate and frigid zones, and is manifest in a certain degree of regularity in the course of their changes.

1. In the northern hemisphere winds which begin as north winds, in gradually advancing pass through N.E. and become more and more easterly. Supposing places

$$\begin{matrix} A & A_{,} & A_{,,} & A_{,,,} \\ B & B_{,} & B_{,,} & B_{,,,} \\ C & C_{,} & C_{,,} & C_{,,,} \\ D & D_{,} & D_{,,} & D_{,,,} \end{matrix}$$

so situated that of A B C D being under the same meridian, the place A is the most northern and D the most southern; of $A\ A_{,}\ A_{,,}\ A_{,,,}$ situated under the same parallel A is the most western and $A_{,,,}$ the most eastern; and that the whole bulk of air contained between $A\ A_{,,,}$ and $D\ D_{,,,}$ is put in motion from north to south; then if the air which had proceeded from $C\ C_{,,,}$ arrives nearly as a north wind in the parallel $D\ D_{,,,}$, that coming from $B\ B_{,,,}$ will arrive as a north-east wind, while that arriving from $A\ A_{,,,}$ will appear still more as an easterly wind. To an observer who

is in D $D_{\prime\prime}$ the vane will thus have gradually turned from N., through N.E., to E.

In the southern hemisphere, winds that begin as south winds, in gradually advancing, pass through S.E., and become more and more easterly. If therefore

$$\begin{matrix} d & d_{\prime} & d_{\prime\prime} & d_{\prime\prime\prime} \\ c & c_{\prime} & c_{\prime\prime} & c_{\prime\prime\prime} \\ b & b_{\prime} & b_{\prime\prime} & b_{\prime\prime\prime} \\ a & a_{\prime} & a_{\prime\prime} & a_{\prime\prime\prime} \end{matrix}$$

designate places of which those being under the parallel $a\, a_{\prime\prime\prime}$ are the most southerly, and those in the parallel $d\, d_{\prime\prime\prime}$ the most northerly, an observer being in $d\, d_{\prime\prime\prime}$ will see the vane turn gradually from S., through S.E., to E.

If the cause which drove the air to the equator continue, the east wind, which is the consequence, or rather the friction derived from the westerly rotation of the earth, will check the current, and the air will acquire the velocity of rotation of the place beneath, and will join it in a state of relative rest. With a continual tendency to stream towards the equator, exactly the same phenomena will be repeated.

Let us now suppose that the descending equatorial current displaces the polar current after it has prevailed for a while. In the northern hemisphere a rising south wind will take the place of the polar current, which will appear to shift from E., through S.E., to S.; in the southern, the equatorial current appearing as a north wind will change the polar current grown more or less easterly from E., through N.E., to N.

In the parallel $D\,D_{\prime\prime\prime}$ of the northern hemisphere the variation hitherto observed will consequently be upon the whole,

N., N.E., E., S.E., S.

In the parallel $d\,d_{\prime\prime\prime}$ of the southern hemisphere, on the contrary, exactly the opposite,

S., S.E., E., N.E., N.

But as air which flows from the equator towards the poles comes from places having greater velocity of rotation to places which move more slowly towards the E., it follows that in the northern hemisphere a southerly wind, in gradually advancing, passes through S.W., and becomes more and more westerly.

In the southern hemisphere, on the contrary, a northerly wind, in gradually advancing, passes through N.W., and becomes more and more westerly. If

D	$D_{\prime}$	$D_{\prime\prime}$	$D_{\prime\prime\prime}$
E	$E_{\prime}$	$E_{\prime\prime}$	$E_{\prime\prime\prime}$
F	$F_{\prime}$	$F_{\prime\prime}$	$F_{\prime\prime\prime}$
G	$G_{\prime}$	$G_{\prime\prime}$	$G_{\prime\prime\prime}$

designate places of the northern hemisphere, of which those in the parallel are the most southerly, and if the whole bulk of air contained between $D\,D_{\prime\prime\prime}$ and $G\,G_{\prime\prime\prime}$ be put in motion from south to north, an observer being in $D\,D_{\prime\prime\prime}$, though he will receive the air coming from $E\,E_{\prime\prime\prime}$ nearly as south, will feel that which proceeds from $F\,F_{\prime\prime\prime}$ more as S.W., and that from $G\,G_{\prime\prime\prime}$ more as W. If in the same way

g	$g_{\prime}$	$g_{\prime\prime}$	$g_{\prime\prime\prime}$
f	$f_{\prime}$	$f_{\prime\prime}$	$f_{\prime\prime\prime}$
e	$e_{\prime}$	$e_{\prime\prime}$	$e_{\prime\prime\prime}$
d	$d_{\prime}$	$d_{\prime\prime}$	$d_{\prime\prime\prime}$

designate places of the southern hemisphere, $g g_{,,,}$ being the most northerly, and $d d_{,,,}$ the most southerly; and if the air between both parallels be put in motion towards the south pole, an observer being in $d d_{,,,}$ though he will receive the air from $e e_{,,,}$ as N., will observe that from $f f_{,,,}$ more as N.W., and from $g g_{,,,}$ more as W.

A westerly wind in both hemispheres will have a retarding influence upon new equatorial currents, and fix them to relative calm. The polar current resuming its sway will change the westerly wind in the northern hemisphere, through N.W., to N.; in the southern, through S.W., to S. Hence the change will be, for the northern hemisphere, S., S.W., W., N.W., N.; for the southern, N., N.W., W., S.W., S.

From the whole of the phenomena observed the following is the result.

In the northern hemisphere the wind turns, (if polar currents and equatorial currents alternate,) *upon an average*, in a direction S.W., N.E., S., through the points of the compass, and it springs back between S. and W. and between N. and E., more frequently than between W. and N. and between E. and S.

In the southern hemisphere, on the contrary, under the same circumstances, the wind turns, *upon an average*, in a direction S.E., N.W., S., and springs back between S. and E. and N. and W., more frequently than between W. and S. and between E. and N.

These consequences have been pointed out by Professor Dove in an interesting Memoir upon the

winds, and confirmed by the discussion of many thousand observations in both hemispheres: and they also coincide with the popular belief, that in settled weather the changing wind follows the course of the sun.

2. Mr. Follett Osler, by observations of his anemometer, (an instrument which has relieved the science of Meteorology from the reproach of being without any accurate means of measuring the force of the wind, and which, when more generally known and adopted, will doubtless solve many of the most important problems connected with this branch of our subject,) has established the important conclusion that the mean hourly force of the wind throughout the 24 hours at Birmingham, without reference to its direction, increases with the increase of temperature. In the curves which he has laid down for exhibiting this effect, the coincidence between the curve of force and of temperature is very remarkable, the temperature preceding the rise of the wind by a short interval*. This observation has been confirmed by Mr. Snow Harris at Plymouth, and by other observers at different stations.

§ 9. ROTATORY MOVEMENTS OF THE AIR.

1. With the particulars of the vertical circulation of the air by which the heat from the surface of the earth passes by convection to the upper regions, we are much more imperfectly acquainted than with those of the horizontal circulation by which it travels from the equatorial to the polar regions. The process is

* *Report, British Association*, 1840, p. 321.

perpetually going on around us, and yet its mechanism in a great measure eludes our observation. It is of a very different nature from that by which the diffusion of dissimilar gases and vapours is effected. The latter is a molecular; the former a mechanical action capable of communicating motion to solid substances in its direction. If we contemplate the motes in a sunbeam, the course of these minute particles of matter will indicate to us the complicated motions of the infinitely subdivided currents upon which they are borne. Every cubic foot of air as it is carried forward by the breeze, will be found to be the seat of intestine action, the conflict of gravity and elastic force. If we extend our contemplation to the ascent of any body of heated air mingled with smoke, the motions of the latter will indicate the same kind of agitation upon a larger scale. The mass seldom or never ascends in a direct line, but rolls over in volumes which have an evident tendency to vertical rotation. The circles of their movements expand as they advance; but the line of their progression is often interrupted by sudden inflexions both upwards and downwards; all indicating by their convolutions the same disposition to circular motion. This ascensional movement, to a certain extent, and in proportion to its energy, checks and tends to neutralize the horizontal impulse; and a corresponding effect would result from a descent of cooled air to the same extent.

It is by these gyratory movements of greater or less extent that the daily variations of the heat of the earth's surface become diffused through the height of

the atmosphere. But air moving with a momentum, however acquired, will turn from any opposing force incurvilinear directions, and thus large bodies of the upper and under currents of the atmosphere may exchange positions, and at times the wind may be observed to blow strongly in a horizontal direction, and at the same time to wheel upwards or downwards in a mass with considerable velocity. Correct observations of such movements would be of great importance to science; but they have been but little attended to, and we are totally devoid of any instrumental means of rendering such observations precise.

2. The air, however, exposed to a large surface intensely heated, will sometimes appear to expand bodily and lift the incumbent strata without breaking into circulating systems tending to equalize the temperature. A body of hot elastic air may thus be brought into a state of unstable equilibrium with the air above it, the natural progression of temperature being deranged. Colonel Sykes thus describes such a state of the air resting upon the heated plains below the Ghâts:—

"The opacity of the atmosphere in the hot months is very remarkable. In looking from the crest of the Ghâts over the Konkun at sunrise, the sky would be free from a cloud, and every object in the Konkun 3000 or 4000 feet below the spectator distinctly visible in the intervals of the fogs: as the day advanced and the heat increased, the air would get misty, but without a cloud in the sky, and by one or two o'clock objects of great magnitude only would be

visible in the Konkun, seen as through a diaphanous medium. The upper surface of this stratum of hot air was horizontal and quite defined. I found it very rarely reach to the height of 4000 feet, and I could invariably foretell the temperature of the coming afternoon above the Ghàts by observing at 9 or 10 A.M. the height of the upper line of the heated atmosphere of the Konkun. If very high at those hours, compared with the preceding day, the temperature would be high; and *vice versâ.*"

Such a state of unstable equipoise must be liable to sudden subversion, and the breaking in of the denser surrounding air will at times produce horizontal revolutions and vortices of greater or less extent, and greater or less intensity, such as are common in all fluids which are acted upon by concurring horizontal and perpendicular forces.

3. The mode by which opposing forces may be thus propagated from the original point of conflict, and some of the laws of their propagation, may be illustrated by a few simple but beautiful experiments, devised by Count Xavier de Maistre*, which may be understood with the aid of the following sketches.

Fig. 13 represents a cylindrical glass of about ten inches in height and four inches in diameter. A depth of about two inches of water is poured into this vessel, which is then filled up with any transparent oil, as of poppies, or with spirits of turpentine. We thus obtain two fluid strata, the one floating above the

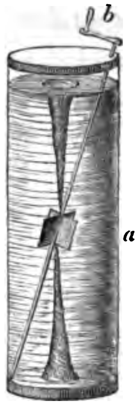
* *Bib. Universelle*, tom. xv., p. 226. First Series.

other. At the top of the jar and wholly immersed in the upper stratum, is placed an arrangement of small vanes (*a*), formed of card or tin-plate, which may be turned upon its axis by the handle (*b*). When it is made to revolve about twice in a second, the water at the bottom of the jar begins in about a minute to rotate and to raise itself in a cone from the centre; and a small column of water rises suddenly as high as the vanes, and has the appearance of a flexible tube of glass. The water is then projected to the circumference of the whirlpool and falls in drops, moving in spiral courses, to the bottom. It is remarkable that

Fig. 13.

Fig. 14.

Fig. 15.



the central column of water rotates with greater velocity than the little mill by which the force is communicated. It is easy to explain the cause of these movements: the rotatory motion of the vanes causes a whirlpool at the surface of the liquid, and the centrifugal force driving it towards the circum-

ference occasions a depression at the centre. The equilibrium of pressure being thus disturbed can only be re-established along the axis of the whirlpool which is not under the influence of the centrifugal force: the lateral pressure of the outside columns, which are higher than the central, raises the liquid in the centre, and as this is again dispersed to the circumference, a continual ascent of the liquid is determined in the axis of the whirlpool.

But this ascending current would be converted into a descending one, if this rotatory motion of the liquid were produced at the bottom of the liquid instead of the surface; because the particles dispersed by the centrifugal force could only be replaced by a current from the surface.

An arrangement may easily be made, as in fig. 14, in which the vanes are exhibited at the bottom of the glass cylinder, and to which rotatory motion may be communicated by a simple contrivance, which may readily be comprehended without a more detailed explanation. When set in motion a small funnel-shaped cavity soon forms at the surface of the liquid, which gradually elongates itself, and its taper end reaches to the revolving vanes. Bubbles of air make their appearance at this point and descend rapidly to the bottom of the vessel, and when the rotation has attained its ordinary velocity, a regular current of air establishes itself throughout the axis of the funnel, the sharp point of which is dispersed by the vanes and rises in a continuous stream of bubbles along the sides of the glass cylinder.

In fig. 15 we have the representation of the phenomena when the rotatory motion is produced in the centre of the liquid mass. Two opposite whirling cones are thus produced, the base of one being at the surface, and that of the other at the bottom of the liquid. A little coloured dust floating in the water will exhibit the ascending current of the latter, while the descending current of the former will be marked by air-bubbles.

Similar phenomena must infallibly take place from analogous causes in aëriform fluids.

Sudden whirlwinds of this nature are common in the atmosphere which rests upon the heated surface of the deserts of Africa, and Colonel Sykes states them to be of frequent occurrence in Dukhun in the hot months.

"A score or more columns of dust, in the form of a speaking trumpet, or water-spout, may be seen at one time chasing over the treeless plains, marking that vortex of heated air which in its whirl carries up dust, sand, straw, baskets, clothes, and other light matters, to a height of one or two hundred yards or more. They are not dangerous, but particularly troublesome in a camp, striking the tents, and scattering about all light loose matters on the surface; and the rushing noise with which they come terrifies horses and induces them to break from their pickets. They are sufficiently powerful also to lift off the grass roof of a hut; and I have known instances of officers' houses having shared the same fate. They appear and disappear with great suddenness; and I have been fre-

quently startled by hearing a loud sound of air rushing from all parts to a central axis, round which it furiously whirls, and on the instant finding myself enveloped in one of these 'devils,' as they are called by Europeans in India."

4. When a similar combination of circumstances takes place in the atmosphere resting upon the sea, the phenomena of the water-spout are produced. "A cone may be perceived to descend from a dense cloud in the form of a trumpet, with the small end downwards: at the same time the surface of the sea under it ascends a little way in the form of white vapour, from the centre of which a small cone, proceeding upwards, unites with that which projected from the cloud; and then the water-spout is completely formed. By the ascending whirlwind a circular motion is given to a small space of the surface of the sea in which the water breaks, and runs round in a whirlpool with a velocity of from one to five knots per hour: at the same time a considerable portion of the water of the whirlpool is separated from the surface in minute particles resembling smoke, with a hissing noise occasioned by the strength of the whirlwind. These particles continue to ascend with a spiral motion up to the impending cloud. In the centre of the whirlwind or water-spout there is a calm, in which none of the small particles of water ascend: and in this, as well as around the outer edges of the water-spout, large drops of rain descend; because in those places the power of the whirlwind not being sufficient to support the ascending particles, they constantly descend in the form of rain."—HORSBURGH.

5. To a similar cause, acting upon a larger scale and with more fearful intensity, must be ascribed those tremendous hurricanes and tornadoes which often range along the West India Islands and sweep the coasts of the United States. "They consist of a revolving movement propagated from place to place, not by bodily transfer of the whole mass of air which at any moment constitutes the hurricane, from one geographical point to another, but by every part of the atmosphere in its track receiving from that before it and transmitting to that after it, this revolving movement.

"If we suppose a column of air intensely heated at a particular point by the intertropical plains of America bodily to rise from the lower stratum of the atmosphere, with an ascensional force enough to carry it into the upper current, retaining the full westerly energy which it has derived from the earth's rotation unsubdued by friction and mixture, nothing is more conceivable than that a *ripple* in its course should thus be caused, and that the portion thus driven upwards should, on its return, strike down far below its usual level into the lower current. All the conditions necessary for a tornado would then arise. A mass of air, animated with enormous velocity, is set to force its way through an atmosphere either quiescent or moving in a contrary direction, a state of things which in the movements of fluids is invariably accompanied with vortices on one or both sides of the moving mass, which continue to subsist and to wander over great tracts long after the original impulse is withdrawn. In such vortices, (which any one may produce on

still water at pleasure) the motions of translation and rotation may have any proportion, but the former is usually slow by comparison with the latter. An amusing illustration of this kind may be witnessed by any one who will station himself at a mill-dam near the sluice when closed, so as to allow the water to escape by some small hole. A funnel-shaped depression will appear on the surface, in which air descends, often to the actual hole of escape, though many feet below the surface; but often, also as an interrupted column, and guiding his eye by this he will perceive all the movements of a tornado represented in every particular by the revolving fluid. So long as the hole is kept open it retains a fixed position, at least at the lower extremity, fluctuating only by a flexure of the column. But if the hole be closed it immediately begins to wander, continuing after a long time, but gradually retreating upwards*."

The bodily rise of a large column of heated air, such as we have supposed, will tend to draw towards its base as to a centre, the air from all the surrounding districts; and it will carry with it a sufficient cause for its continual expansion and ascent, in the vapour with which it is mixed, and which, by its rapid precipitation, must give out its latent heat. The centre of the vortex thus produced, may either be stationary, or progress with different degrees of velocity according to circumstances. The barometer would of course be depressed everywhere within its range, and the more so the nearer it were placed to its centre.

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* Herschel. *South African Report.*

It has been remarked by Mr. Redfield, who has analyzed the recorded particulars of the progress of twelve of these terrific gales, that in the northern hemisphere these atmospheric phenomena generally occur at about the northern limit of the trade winds, and that the direction of the revolving motion of the tornado is always the same, being invariably from left to right as you enter its circle, or proceed towards the heart of the gale, and from right to left as you leave it or recede from the centre.

Such an observation, if fully confirmed, would be of incalculable advantage to navigation, as a seaman in such a storm would never be at a loss in what direction to expect the wind, and veer a point, on which the safety of his vessel would essentially depend. Such a knowledge would at once direct him how to steer, so as to get as far as possible out of the way of the centre, where the greatest intensity of the gale and the most sudden reversal of the wind are to be expected.

Colonel Reid, by a careful and laborious examination of the subject*, has established the fact that similar revolving storms occur in the southern hemisphere and in the Indian seas. In the southern hemisphere the direction of the tornado is invariably opposite to that in the northern, namely, from right to left; and hence there cannot be a doubt that their force and direction is primarily derived from the upper opposite equatorial currents suddenly precipitated into the lower regions with the full momentum due to

* Reid *On the Law of Storms*.

the excessive rotatory movement of the equator. It must, however, not be forgotten that such storms are comparatively rare exceptions to the general course of atmospherical phenomena. The spirit of generalization has gone too far in suggesting not only that all storms follow the law which has thus been derived from the careful collation of the phenomena of tornadoes, but that the variable winds of all climates have the same origin.

Colonel Reid has remarked that "that impulse which causes the diurnal rotation of the earth on its axis, would seem to act with less effect on the aërial atmosphere than on the solid globe; and the difference of their velocities is one of the causes of the regular easterly trade winds. Although the motion of the fluid ocean is more rapid than that of the atmosphere, still it is not so rapid as that of the solid globe; and hence the apparent cause of the primary movement of the great oceanic currents. The globe revolving from west to east leaves the ocean as well as the atmosphere behind it."

But this statement is not correct; for supposing the progress of the air towards the equator to cease, friction would almost immediately communicate to it the full motion of rotation due to the latitude at which it stopped, after which it would revolve quietly with the earth and be at relative rest. It is the lower meridional current which transports the slowly rotating fluid of high latitudes to the quickly revolving surface of lower latitudes, behind which it lags for a time: it is the upper and opposite meridional current which carries the quickly-whirling at-

mosphere of the equator towards the quiescent poles. By slowly cooling and gently subsiding it loses part of its momentum by friction and other opposing forces, and deflects the lower current with moderate power; but sometimes from disturbing causes bodily displaces the latter for a time, or still more rarely precipitates itself almost vertically upon the earth with unmitigated velocity.

6. We have already explained the reason why the variable winds of extra-tropical regions appear upon the average to turn through a particular course in their changes, which is opposite in the two hemispheres, and identical with that of the tornadoes which we have been considering; but such an apparent circuit of the former must not be confounded with the real rotations of the latter. There is nothing *vortical* in the character of the first, and the circuit is made up by the absolute motion of the air on one side, and by its relative motion (or the absolute motion of the earth) on the other, but in the second the vast body of air whirls from a real centre of rotation (although perhaps in a state of translation) and with a real centrifugal force.

There can be no doubt, moreover, that violent storms of wind arise which are totally independent of a whirling motion, and often may be referred to the bodily concussion of the upper and lower currents alternately displacing each other and bearing with them the variable influence of the earth's rotation. Captain Fitzroy, in his interesting account of the surveying voyages of His Majesty's ships *Adventure* and *Beagle*, in discussing this very point, observes

(App. vol. ii. p. 277), "I never myself witnessed a storm that blew from more than fifteen points of the compass either successively or by sudden changes.

"In most if not all of the storms to which I can bear any testimony, currents of air arriving from different directions appeared to succeed each other or combine together."

7. Severe squalls of wind often arise from local circumstances of very limited extent; and Captain Basil Hall has remarked, that in the interval between the two trade winds which is called *the Variables*, he has observed a ship at a distance of five or six miles struck by a gust of wind which was some hours in reaching his own vessel, although when it arrived it blew with a velocity of twenty or thirty miles per hour, and in the direction towards him. The very instructive *Account of the Arctic Regions*, for which we are indebted to Captain Scoresby, and the Journal of Captain Parry, have made us well acquainted with the interesting regions of perpetual ice and snow. In our hypothetical statement of the progression of the earth's temperature, we have supposed no greater cold to prevail than that of 0° at the poles, but the experience of our intrepid navigators has proved that a cold of 50° greater intensity sometimes prevails in latitudes still far removed from the 90th degree. The density of the air is, of course, proportionately increased, and its sources of inequality multiplied. When the sun is above the horizon, it produces comparatively little effect upon the icy mountains, while the neighbouring seas are warmed by its unceasing

influence. The extremes of heat and cold will sometimes prevail within a very limited compass; and forcible winds will blow in one place, when, at a distance of a few leagues, gentle breezes prevail. "Ships, within a circle of the horizon, may be seen enduring every variety of wind and weather at the same moment: some under close-reefed topsails, labouring under the force of a storm; some becalmed and tossing about by the violence of the waves; and others plying under gentle breezes from quarters as diverse as the cardinal points." The fluctuations of the barometer are also great and sudden, proving what theory would have induced us to conclude, that the irregularities of these regions extend to the higher strata of the atmosphere.

§ 10. OSCILLATIONS OF TEMPERATURE.

The modifying circumstances which cause the real temperature of a place to vary from its true solar temperature are so numerous and diversified, that it would require a separate volume to follow them in detail. It must suffice for our present general purpose to indicate the principal causes which give rise to the oscillations around the mean.

1. The temperatures of different latitudes are influenced by the mixture of different winds; the vicinity of seas (which are generally immense reservoirs of an almost invariable heat, but sometimes are themselves affected by hot and cold currents of vast extent); the unequal and varied surface of the land;

its chemical nature; the colour, the radiating power, and the rate of evaporation of the soil; the direction of chains of mountains, which act either in favouring the play of descending currents, or in affording shelter against particular winds; the shapes of different countries, their mass and prolongation towards the poles; the quantity of snow which covers them in winter, their temperature and their reflection in summer; and finally the fields of ice, which form circumpolar continents, variable in their extent, and whose detached parts, dragged away as ice-bergs by currents, modify, in a sensible manner, the climates of the temperate zones.

The quantity of heat which any point of the globe receives is, however, much more equal during a long series of years than we should be led to conceive, from these varying circumstances, and the uncertain testimony of our senses; the greatest aberration from the mean of any year scarcely amounting to 3°, in places where thermometric observations have been most carefully registered.

The isothermal lines to which we have already referred, and which are represented in the map of the northern hemisphere, exhibit the unequal effect of the distribution of land and water upon the mean annual temperature of the American, European, and Asiatic continents. This inequality is still more apparent in the differences of the seasons from the equator to the polar circle; for the distribution of heat over different parts of the year differs greatly in the same isothermal line. This is remarkably exemplified in the following Table:

TABLE XLIX. *Differences of the Seasons from the Equator to the North Polar Circle.*

Isothermal line of	Cis-Atlantic. Long. 1° W. and 17° E. Mean Temperature. Winter.	Summer.	Diff.	Trans-Atlantic. Long. 58° —— 72° Mean Temperature. Winter.	Summer.	Diff.
68°	59°	80·6°	21·6°	53·6°	80·6°	27·0°
59	44·6	73·4	28·8	39·2	78.8	39·6
50	35·6	68·0	32·4	30·2	71·6	41·4
41	24·8	60·8	36·0	14·	66·2	52·2
32	14·0	53·6	39·6	1·4	55·4	54·0

2. The extremes of temperature in the different climates of the earth are widely separated from each other, and the range of the thermometer is always greatest in the interior of the continents within the tropics. Mr. Campbell, in the country of the Botchuanas, saw the thermometer at 8 A.M. at 28°, and at 84° at noon. Mr. Bruce records a temperature at Gondar of 113°. The thermometer at Benares rises to 118°; at Sierra Leone the thermometer, on the ground, has been seen to rise to 138°; and Humboldt gives many instances of the temperature of the torrid zone rising to 118°, 120°, and 129°. At one time he found the temperature of a loose coarse-grained granite, in the sun, 140°·5. In the Dukhun, at a height of 3090 feet above the sea, Col. Sykes once saw the thermometer in the shade at 105 ; the range of the thermometer generally being from 93°·9 to 40°·5.

But these extreme degrees of heat are by no

means confined to the intertropical regions. At Berne, in Switzerland, the range has been from $-24°$ to $95°$; at Montpellier, in France, the thermometer stood for some days at $100°$; and at Paris it has even reached $101°$. At the latter place the range of the thermometer between 1790 and 1795 was from $-8°·6$ to $99°·6$. In St. Petersburg the thermometer has been as low as $-35°·7$, and as high as $91°·4$. The range of the thermometer, from October, 1824, to June, 1825, in Port Bowen, was found by Captain Foster to be from $+47$ to -45.

These extremes of temperature, which would cause the specific gravity of the air to vary from 1167 to 863, may serve as a kind of measure of the disturbing causes which interfere with the velocity and local direction of atmospheric currents, and other phenomena, the calculation of which has been founded upon mean results.

3. We are presented by nature with a magnificent registering thermometer, upon a large scale, which places the results of such interferences in a still more striking point of view; this is the snow which caps the tops of the lofty mountains which in all quarters of the globe penetrate to a sufficient height into the upper regions of the atmosphere. It is obvious that the decreasing progression of temperature, as we ascend through the air, which we have established by our previous researches, must conduct us at last to a region of perpetual congelation, and we may imagine a curved surface to pass through the least heights at which the snows are preserved during the entire year,

and which has been denominated the *plane of perpetual snow*. If the temperature of the globe, in its different latitudes, had been uniformly that of the mean temperatures of the same latitudes, the range of this plane through the atmosphere would have partaken of the same degree of uniformity. It would have attained its greatest elevation in the equatorial regions, and gradually descending towards the earth's surface, it would at last have met it in some fixed points of the polar zones. Something of this character it still preserves; but a great variety of causes interfere with its regularity. The neighbourhood of the great oceans alone contributes a partial uniformity to it, but the unequal distribution of heat, arising from the uncertain conditions of the earth's surface, and the anomalous effects of mountains and plains, disturb it on every side. An attempt has been made to represent the relative height of this plane from the equator to the poles upon the Maps; but they are necessarily laid down without any regard to their proportions to the radius of the earth.

It is in the equatorial regions of the New World that we meet with the most magnificent examples of this plane. The investigations of Humboldt have fixed the height of the perpetual snows at the equator at 15,803 feet, which nearly corresponds with the height of the point of congelation, as shown in the equatorial column, as calculated in Table VII. The following Table contains the results of his measurements of the lines upon six of the loftiest summits of the Andes.

TABLE L. *Altitude of the lower limits of perpetual Snow.*

Summits of the Andes.	Latitude.	Feet.
Rucupichincha - -	0° 10′ S	15,700
Huahuapichincha -	.. ..	15,732
Antisana - - -	0 31	15,943
Corazon - -	0 32	15,719
Cotopaxi - - -	0 41	15,924
Chimborazo - -	1 28	15,802
Mean -	.. ..	15,803

In the immediate vicinity of the equator a small change in the latitude produces no sensible difference in the height of perpetual snow, but as observations become extended towards the northern border of the torrid zone, the difference becomes perceptible. According to a trigonometrical measurement made by the same eminent philosopher on the snows of Popocatepeti, one of the lofty mountains which rise from the elevated plains of Mexico in latitude 18° 59′, the inferior limit was found to be 14,977 feet. On the borders of the torrid zone, therefore, the plane has only lowered about 800 feet. From latitude 19° to the parallel of 30°, we are not acquainted with the altitude of a single snowy peak. Of the mountains of Mexico not one penetrates the plane of perpetual snows between 19° 12′, and 40° north. A portion of the zone, however, in the eastern hemisphere, comprised between the latitude of 27½° and 36°, embraces the stupendous range of the mountains of Himalaya. Mr. Colebrook first made the remark, derived from the observations of Captain Webb, that the inferior limit of perpetual

congelation does not descend on these mountains as low as theory would lead us to conclude, and this was followed up by a discussion of Captain Webb's observations by Humboldt, who published an admirable Memoir upon the subject of the inferior limit of the perpetual snows upon the Himalaya mountains. The mountains which enclose the dell of the Taglá river are between 19,000 and 20,000 feet in elevation, and are but just tipped with snow. Other determinations have been made connected with the elevated points and plains on which the perpetual snows are never found, but they afford indirect evidence upon the point. By observations made on the crest of the Nitee pass, Captain Webb found the Sutledge to flow in a plain elevated 14,924 feet above the level of the sea, but so far is it from being buried in perpetual snow, as theory would have suggested, the banks of the river afford the finest pasture for myriads of quadrupeds throughout the year.

The great elevation of the plane of the perpetual snows in these regions is doubtless the effect of the radiation of heat from the elevated plains of Tartary; but we know too little of the nature of terrestrial radiation to enable us to form an estimate of its influence except from the fact now under discussion.

The chains of Caucasus and of the Pyrenees occupy nearly the same average latitude, and a comparison of the perpetual snows on the two ranges, places the fact which we are illustrating in a striking point of view. Mount Kasbek, in the first of these chains, is scarcely half a degree more south than the

Pyrenees, and yet the perpetual snows are supported on its northern slope, according to the measurements of Englehardt and Parrot, at an elevation of 10,552 feet, whereas the highest estimate of this limit in the Pyrenees, by Humboldt, is 8400 feet. The cause of this anomaly is again to be attributed to the peculiar position of this mountain chain; principally from the effects produced on its temperature by the very extensive plain which ranges from its base through Moscow to the Icy Sea. That an increase in the altitude of the perpetual snows may be reasonably ascribed to this cause, may be inferred from the great elevation of the isothermal curves on this continent. Humboldt has remarked that at Moscow, in latitude 55° 45′, and on the isothermal line of 40°·1, the temperature of the hottest month rises to 70°·5; whereas at Paris, in latitude 48° 50′, on the isothermal line of 51°·1, the warmth of the hottest month amounts in general but to 65°·3.

Saussure has fixed the limits of perpetual snow upon the Alps at a mean elevation of 8793 feet; but considerable differences exist between the northern and southern sides of these mountains.

The Carpathian mountains, situated between the parallels of 48° 55′ and 49° 15′, and therefore to the north of the Alpine range, are also under the influence of the neighbouring plains, and the perpetual snows are found at a much higher elevation than on the mountains of Switzerland. Mount Pilatus, for example, in the latter country, although only 6927 feet above the sea, is covered with perpetual snow; whereas

not one of the peaks of the Carpathian range is found to be so, although they attain a height of 8464 feet.

According to Von Buch, Sweden presents few examples of mountains upon which the snow rests in summer; but Norway, consisting of a range of mountains extending from one of its extremities to the other, presents many examples of the perpetual snows. In latitude 61°, the lowest range is about 5600 feet; but the Melderskin, and Solen-Nuden, upon the sea coast, present examples of the sudden depression of the snow line. The elevation of the former is 4860 feet, and of the latter 4796 feet, and the summits of both are covered with everlasting snow.

In the latitude of 70° Von Buch assigns to the snow-plane a height of 3517 feet; but between Alten, to which this elevation belongs, and Hammerfest, upon the island of Qualoe, the snow-line sinks to 2345 feet, affording the remarkable example of a depression of 1172 feet in an interval but little exceeding one degree; whereas between Tillefieldt and Alten, a space occupying ten degrees of latitude, the perpetual snows sink but 2025 feet.

These heights are of course subject to oscillations from the vicissitudes of the seasons, and these are greater as we proceed from the equator towards the poles. They are estimated without reference to the phenomena of glaciers, or those enormous masses of ice which are created in the lapse of time by the alternate melting and congealing of vast fields of snow, which for this purpose must rise considerably above the limit of perpetual congelation; an enormous

pressure from above forces the inferior parts of the icy volumes into the valleys below, where they undergo little change during the lapse of centuries; the alterations produced by their gradual thaw being compensated by other masses formed in the cold repositories above. It is easy to perceive that as we distinctly trace the influence of the subjacent plains upon the plane of congelation, so the vast accumulations of snow upon the lofty mountain ranges which penetrate far beyond it, must produce a sensible and important reaction upon the districts within their range. The further investigation of these effects belongs to the history of particular climates, upon which it is not my present intention to enter.

§ 11. VARIATIONS OF AQUEOUS VAPOUR AND RAIN.

The vapour in the atmosphere is obviously dependent in a great measure upon circumstances of temperature; and limits have been fixed, as has been shown, beyond which the aqueous ingredient of the mixture cannot pass, whereby an undue accumulation of moisture on the one hand, and a state of long-continued dryness on the other, are both prevented. But the relative positions of land and water have also a most important influence upon its distribution and force.

1. The tension of vapour given off in the process of evaporation is determined, not by the temperature of the evaporating surface, but by the elasticity of the aqueous atmosphere already existing.

I have often endeavoured, by means of the hygro-

meter, to detect, within a limited circle, a difference in the elastic state of the vapour incumbent upon different surfaces of various temperatures, but without success: the rising vapour was always of the same quality, whether from water, vegetation, or ploughed land; in sun-shine, or in shade. For the same reason, the dew-point is but little affected by the increase of daily temperature from morning to afternoon, or by its subsequent declension at night. But one of the most remarkable confirmations of the fact was ascertained by Colonel Sabine upon the coast of Africa. While the sea-breeze was blowing upon that station, the hygrometer denoted the dew-point to be about 60°, but when the wind blew strong from the land, it approached, in its characters, to a Harmattan; and the point of precipitation was not higher than 37°·5, the temperature of the air being 66°. Notwithstanding the heat of the evaporating surfaces in the interior of that continent, the burning sands of its deserts yield so little vapour, that it becomes attenuated by its diffusion, and there can be little doubt that the aqueous atmosphere incumbent upon it, (and which, when wafted to the coast by the rapid motion of the air, constitutes the true Harmattan,) is not of greater force than that which rests upon the polar seas; and that while the heat of the air sometimes approaches to 90°, the constituent temperature of the vapour is below 32°.

During the blowing of a full Harmattan, indeed, it has been found that salt of tartar (carbonate of potassa), which had imbibed moisture so as to run

upon a tile, became perfectly dry upon two or three hours' exposure to the wind; which fact indicates a dew-point considerably below the one just mentioned*.

Upon a mean of ten months' observations, by Colonel Sykes, at Dukhun, during the monsoon which flows from the sea from June to October, the dew-point was 68°·8, indicating a force of vapour of 0·699 in. A mean of nine months' observations in the same country during the dry months gives a dew-point of 54°; elasticity of vapour ·417 in. The mean temperature of the air, taken at the same time, was, for the former period, 77°·6, and for the latter, 76°·9, so that the depression of the dew-point was evidently not owing to depression of temperature, but to the influence of the land.

Even in the insular situation of Great Britain, the difference in the dew-points of the winds which blow from the side of the great Atlantic, and from that of the continent of Europe, is clearly traced; and although accurate observations are much wanting, common experience has proved that in all countries the winds which have blown over large tracts of land are much drier than those which proceed from the sea.

2. But although the elastic force of the atmosphere of vapour is chiefly under the control of the temperature of the air, the former is not without a reaction upon the latter. We have already shown that the latent heat evolved in the act of condensation raises

* *Phil. Trans.* vol. lxxi., p. 25.

the temperature of the higher regions, and tends to destroy the regular progression due to the change of density; and this is also the case when a saturated wind first breaks upon a line of coast and precipitates its moisture. Hence the western coasts of extra-tropical lands have a much higher mean temperature than their eastern coasts. This difference is extremely striking between the western coast of North America and the opposite eastern coast of Asia. The general western current which prevails after sweeping the surface of the ocean, in its passage over the land, deposits more and more of its aqueous particles, and by the time that it arrives upon the eastern coasts is extremely dry: as it moves onwards it bears before it the humid atmosphere of the intermediate seas, and arrives upon the opposite shores in a state of saturation. Great part of the vapour is there precipitated, and the temperature of the climate raised by the heat evolved.

3. We have two natural hygrometers upon a large scale, to whose indications we must next turn our attention:—these are, the clouds and rain; but before we proceed to collect and review the recorded results of observations upon these common but ill-understood phenomena, let us turn our attention a little more particularly to the suggestions of our theory upon the subject.

The explanation which Dr. Hutton, of Edinburgh, gave of the formation of rain, has obtained almost universal acceptation. He supposed it to result from the simple mingling together of great beds of air of

unequal temperatures differently stored with moisture. "A volume of air of a given temperature can be charged with only a limited portion of *humidity*, and so long as the temperature remains unchanged the *moisture* cannot be augmented. As the air cools it approaches to a state of saturation, and is disposed to part with some of its humidity; and on the contrary, when heat is gained at any time by it, the power of receiving more moisture is at the same time obtained, while the union of two volumes of unequal temperatures must chill the one and warm the other, the former will resign some of its moisture, and the latter will be disposed to receive it; and had the order of nature permitted these opposite conditions of humidity and temperature to be exactly balanced, the united volume might have preserved its moisture unchanged, and no portion of the vapour whatever have been rendered visible. We have seen, however, that while the temperature slowly mounts by uniform arithmetical degrees, the moisture necessary for saturation ascends in a more rapid geometrical progression, and though two saturated volumes of unequal temperature, may by their union afford a mean degree of heat, a mean degree of moisture cannot result, but some quantity will be found in excess beyond what the mean temperature requires. This quantity, sometimes more and sometimes less, according to the temperatures of the mingling volumes, must be discharged in the shape of rain, for the moisture which the air cannot support ought of necessity to descend.

"Thus, let it be required to mingle two volumes of

air of the temperature of 40° and 60° each, being saturated with humidity. The force of vapour at these temperatures is known to be respectively about 0·263 and 0·524 inches of the mercurial column. The compound mixture will evidently have a mean temperature of 50°, and the mean of the elastic forces is at the same time 0·393 inches. But if we now enquire whether air at the temperature of 50° requires an elastic force of this last-mentioned magnitude to saturate it entirely with vapour, we shall find that it does not; and that at the mean temperature here referred to, the measure of entire saturation is really 0·375 inch. The difference of the two columns, or 0·018 in. of mercury, is hence the amount of moisture that must be precipitated in some way or other from the compound mass."

4. But upon close examination this will appear to be by no means a satisfactory or sufficient explanation of the process of nature. Indeed, in these days of general steam, every one may have an opportunity of convincing himself from the action of an engine, that, even when vapour of high pressure is suddenly mixed with the atmosphere it is very seldom precipitated in the form of rain. A copious cloud is, indeed, formed, which speedily evaporates and "vanishes into thin air." The fact is, that one most important part of the process has been left out of consideration, namely, the enormous quantity of latent heat which is instantly disengaged by the condensation. We have already made a rough estimate of its amount (p. 116, *et seq.*), and shown its heating effect upon the

air in which it is disengaged. The cloud is no sooner formed than it is again evaporated; the warmed atmosphere being prepared to support steam, not at once of the full elastic force of the hottest volume of the mixture, but considerably higher than that of the coldest.

By slow degrees enormous tracts of the atmosphere have their natural progression of temperature thus subverted and raised, and are made to support vast beds of moisture, far exceeding in amount what could exist in the normal state of the permanent gases. Fresh stores of vapour pour in on every side; the process goes on, but the counteraction of the air against this coercion increases in energy; the precipitatory process prevails, while evaporation becomes more languid; the clouds increase, slowly approach the earth, the different strata inosculate with each other, and at length descend in rain. The atmosphere gradually discharges its load as the natural progression of temperature is restored. In such a saturated state of the atmosphere an artificial shower of rain may be formed by the escape of steam into the air, and occasionally under such circumstances the rushing vapour from steam-vessels is partly returned in large drops upon the deck.

Mr. Monck Mason, in his aëronautic excursions, has remarked that "whenever, from a sky completely overcast with clouds, rain is falling, a similar range of clouds invariably exist in a certain elevation above; and that, on the contrary, whenever, with the same apparent condition of the sky below, rain is altogether

or generally absent, a clear expanse of firmament, with a sun unobstructed by clouds, is the prevailing character of the space immediately above."

The transport and mixture of the vapour is partly effected by the convection of the air, and partly by its own diffusive energy. It is carried aloft by the horizontal winds from the hot, moist, regions of the globe towards the colder, dry, regions, and it rises from the evaporating surfaces in those rotatory vertical motions which we have noticed as effecting the mixture of the hot and cold particles of the air. But besides these mechanical processes, the process of diffusion, by which it permeates the particles of air without disturbing their relative position, is perpetually and energetically acting to spread it from points of greatest to those of least tension, and thus tending to equalise its pressure.

5. The attentive and systematic study of the clouds, as they form, dissolve away, and re-form in their great successive planes of precipitation, is one of extreme interest, and if properly followed up would do much to explain what is still obscure in the process of nimbification. Their language is, however, very difficult to decipher, from the difficulty of understanding the perspective of their ever-changing masses. They are never at rest, but as they float upon the wind they may be observed to have proper motions of their own. Different portions of their masses will be found to circulate, as the air, heated by the act of precipitation, rolls over to mingle with the cooler masses with which it is in contact. It is this rolling motion which gives the infinitely varied rounded contours to the

cumulated heaps, which appear fixed in the distance, but which a nearer examination proves to be in a state of perpetual change. The process of diffusion is also distinctly marked by the fibrous streaks which may often be seen to shoot and expand from different centres before they have time to accumulate into the larger wreaths or denser rolling masses.

The apparent permanency and stationary aspect of a cloud is an optical deception, arising from the solution of moisture on one side of a given point, as it is precipitated on the other. No phenomenon is more common amongst mountains, or upon hills by the seaside, than clouds upon the summits which appear to be perfectly immoveable, although a strong wind is blowing upon them at the time. That this should be the real state of the case, is clearly impossible, because so attenuated a body as constitutes the substances of the clouds must obey the impulse of the air. The real fact is, that the vapour, which is wafted by the wind, is precipitated by the contact of the cold mountain; and is urged forward in its course, till, borne beyond the influence which caused its condensation, it is again exhaled and disappears: an analogous process is perpetually going on with the clouds in their great planes of precipitation and evaporation.

It has been maintained by high authority, and by De Saussure amongst others, that the very minute spherules of which the clouds are composed, are hollow, and consist of a thin envelope of water filled with air or elastic steam, and the name of *vesicular vapour* has been given to vapour in this condition.

But the correctness of this opinion has scarcely been maintained by sufficient evidence. Amongst the arguments made use of is the impossibility of globules of mere water floating in the air, as the masses of the clouds appear to do, on account of their greater gravity, but there can be little doubt that the individual particles of which the clouds are formed, are in a state of continual slow subsidence; that falling into a warmer strata of drier air they are reconverted into vapour as they fall; and that this evaporation upon their lower planes being accompanied by continual precipitation at a higher plane, confers the appearance of stability.

The different forms of clouds which have been so happily described and named by Mr. Luke Howard, no doubt greatly depend upon the relative adjustments of the evaporating and precipitating processes in their respective planes; but they must also be modified by their electric relations.

6. The diffusive power of the vapour is sometimes attested even against the force of a gentle wind, and the dense fogs which infest the banks of Newfoundland are often observed to advance in a direction contrary to the breeze.

The following passages from the works of De Luc, (who was probably one of the most accurate observers of nature that ever existed, and who seldom indeed allowed any hypothetical considerations to warp his description of what he had observed,) will afford a complete illustration of the preceding remarks, although they were penned by him to support a very different hypothesis.

"Si l'on ne fait qu'une légère attention à la surface de ces brouillards, vus des montagnes, pour en jouir comme d'un beau spectacle, on peut penser qu'ils sont permanens; que l'évaporation est arrivée à son maximum à la surface des eaux, parceque l'air est parvenu à l'humidité extrême; et que les vapeurs vésiculaires qui troublent la transparence de cet air restent les mêmes durant des semaines ou même des mois; c'est-à-dire, tant que le brouillard se conserve à une même hauteur. Mais le phénomène diffère beaucoup de cette première apparence: l'évaporation continue à la surface des eaux, les vapeurs vésiculaires qui s'en forment montent sans cesse, et une nouvelle évaporation a lieu à la surface des brouillards. C'est un spectacle aussi amusant qu'instructif, que celui que fournit cette surface, vue d'un lieu peu élevé au-dessus d'elle, et dans une grande vallée, où l'on ait, à quelque distance, des montagnes rembrunies par des fôrets de sapins. Une telle vallée, éclairée par les rayons du soleil, semble être comblée de coton, filé dans toute sa surface par des êtres invisibles en fils invisibles: il s'y fait partout des tumeurs, semblables à celle que produit une fileuse sur sa quenouille en tirant le coton pour former son fil, et elles disparoissent successivement en se dissipant dans l'air. Quelquefois ces tumeurs s'allongent et se separent de la masse en tendant à monter: on les voit alors s'étendre comme un paquet de gaze qui se déploie, et peu à peu elles disparoissent. Les brouillards se forment donc constamment à la surface des eaux et du sol; mais constamment aussi ils se dissipent dans l'air supérieur; et

cependant on n'aperçoit point que l'humidité y augmente*."

"Depuis que mes idées ont changé sur la cause de la pluie, j'ai fort souvent fixé mon attention sur les nuages, et j'ai reconnu très évidemment, qu'ils s'évaporent, même tandis qu'ils grossissent. Si l'on fixe ses regards sur leur bord découpé, qui, lorsqu'il a pour fond l'azur du ciel, présente mille figures singulières, celles que l'imagination leur prête alors, peut aider à l'examen dont je parle, en rendant leurs changemens plus frappans. Il arrive souvent, que la partie sur laquelle on fixe son attention, se dissipe au lieu même où l'on a commencé à l'observer: souvent aussi on la voit s'étendre, sans que la totalité du nuage se meuve, et elle ne se dissipe pas moins durant cette extension. Quelquefois, tandis que l'un des festons du nuage se dissipe, on en voit d'autres se former, s'étendre, produire eux-mêmes de nouveaux festons par où le nuage grossit: d'autres fois il diminue; et alors tous ses festons s'évaporent successivement et il n'en acquérit de nouveaux, que parcequ'il se découpe: on aperçoit en même tems, qu'il devient plus mince, et il disparoit enfin totalement. * * * C'est ce qui m'a conduit à penser qu'il y a en effet dans l'air, une source générale de vapeurs, qui en fournit en certaines circonstances; que ces vapeurs sont produites au lieu même où se forme un nuage; que c'est par la durée de cette production de vapeurs, que les nuages subsistent, s'aggrandissent même, quoiqu'en s'évaporant tout le tour; et

* *Idées sur la Météorologie*, tom. ii. p. 78—80.

ıe lorsqu'ils se dissipent, c'est que leur evaporation est plus réparée par la formation de nouvelles peurs*."

The theory of the *solution* of moisture in the air, hich was the only one that existed at the time hen De Luc wrote, could not at all account for is "production of vapour at the very place where cloud is formed," which the sagacity of this eminent philosopher detected; but the Daltonian theory of *diffusion* accurately explains it.

7. The rain in different localities must depend very much upon the changes of the wind, and the retardation or acceleration which they offer to the progress of vapour. But another cause of this inequality arises from the unequal supply, which the process of evaporation furnishes, from the irregular surface of the globe. This cannot be placed in a stronger light than by the following considerations. The Caspian Sea, which is placed in the centre of the largest continent of the world, receives the precipitations of an immense tract of the atmosphere by means of the rivers which flow into it, and drain the neighbouring countries. The whole of this supply is again returned by evaporation, and its waters have no other means of escape. The lakes of North America, situated in nearly the same parallel of latitude, and at the same altitude, receive the drains of a much less space; but annually roll an immense volume of water to the ocean. We are thus furnished with a hygrometer upon a large scale, by

* *Idées sur la Météorologie*, tom. ii. pp. 117, 118.

which we may judge of the state of saturation of the two atmospheres. The difference can arise from no other cause than the proximity of the surrounding seas in the latter situation, which furnish an inexhaustible source of vapour which is deficient in the other. It is for the same reason that less vapour is contained in the atmosphere above a continent than above the ocean, although more rain falls in the former situation than in the latter, under the same latitudes, owing to the greater vicissitudes of temperature. Much of the aqueous atmosphere which is formed from the great deeps, is thus drawn off towards the continents, where a scarcity of water occasions an inadequate pressure of the vapour.

8. Rain seldom occurs in the constant trade winds, but abundantly and constantly in the adjoining latitudes, particularly in the intermediate regions of the calms.

Between the tropics, the elasticity of the aqueous vapour reaches its maximum amount, and within these limits only, rises to any extent into the upper current of the atmosphere. Its own force, therefore, which is laterally exerted, is assisted by the equatorial wind, and it flows to the north and south; a portion, however, being precipitated befoie it sets out for its opposite course towards the two poles. No accumulation can therefore be formed; and the temperature being remarkably steady, seldom varying more than two or three degrees, precipitation can but seldom occur from the two established currents.

The continental parts, however, of the same regions,

being liable to greater vicissitudes of heat, as we have shown, are subject to rainy seasons, which are periodical, like the monsoons of the same climates, and are governed, as they are, by the progress of the sun in declination. The condensation, while it lasts, is in proportion to the density of the vapour, and is violent beyond anything that is known in temperate climates. The alternate seasons of fine weather are distinguished by cloudless skies and perfect serenity.

The heavy rains which fall in India always take place during the shifting of the monsoon, and while they last the winds are always variable.

The progress of these phenomena has been described by the Baron de Humboldt in that part of South America which is situated to the north of the line, and may be taken as an illustration of the intertropical seasons; bearing in mind that on the opposite sides of the equator the succession is reversed.

On the borders of the Orinoco the sky is perfectly serene and cloudless from December to February; the wind blows from the E., or E.N.E.; the air is dry, and vegetables are deprived of their leaves. Towards the end of February or the beginning of March, a slight veil of haze appears upon the horizon, and gradually extends to the zenith. The trade wind blows with less force, and is sometimes interrupted by calms. By degrees clouds collect in the S.S.E., and mountainous cumuli often traverse the sky with great velocity. Towards the end of March lightning flashes in the S., and a wind sets in from the W., or W.S.W., and continues several hours of the day. The lightnings

increase, especially at sunset, and are the sure sign of the approach of the rainy season, which sets in at the end of April. The sky becomes turbid, and its colour gray instead of clear blue. In the afternoon, at the moment of greatest heat, a storm, accompanied by violent rain, rises over the plain country. At first the clouds form and the rain is discharged only during the hottest hours of the day, and disappear at night. But as the season advances, and especially during the time that the sun is in the zenith, both commence in the morning. Towards the end of the wet season, however, they are again confined to the afternoon.

It would appear that these violent rains, so evidently connected with the rising temperature, as well as those which occur in the region of calms upon the broad oceans, depend upon the rising columns of rarefied air, which carry up with them in their ascent the highly-elastic vapour of these hot latitudes. As they rise the air assumes the equivalent temperature due to the elevations to which it ascends, which, falling rapidly below the constituent temperature of the entangled steam, precipitates the excess in rain. The moisture is thus returned nearly to the surface from which it rises.

9. The rain in extra-tropical regions gradually loses its periodical character, and the maximum quantity no longer falls when the sun is in the zenith, but rather in the winter months, when its influence is least, or on the decline. It proceeds principally from the vapour transported by the horizontal currents of the atmosphere fed by the evaporation of the subjacent surface.

In the temperate climates, however, the quantity of vapour in the atmosphere, in the different seasons of the year (measured on the surface of the earth and near the level of the sea), follows the progress of the mean temperature.

This observed result might readily have been deduced from theory; for the rate of evaporation and the quantity of vapour which the air can support are both obviously dependent upon the same progression. But this connection is not discoverable in short periods of observation; and the changes of diurnal temperature do not immediately affect the quantity of elastic vapour. The air, at night, generally reaches the point of deposition, even at the surface of the sea, but in a very gradual manner: and at the same time the supply from evaporation ceases. The progress of the vapour in fine weather may often be very satisfactorily traced by means of the clouds. During the heat of the day it rises from the surface of the land and waters, and reaches its point of condensation in greater or less quantities at different altitudes. Partial clouds are formed, in different parallel planes, which maintain their relative distances. The denser forms of the lower strata, as they float along with the wind, indicate the greater abundance of the precipitation at the first point of deposition, while the feathery shapes and lighter texture of the upper attest a rarer atmosphere. These clouds do not increase beyond a certain point, but often remain stationary in quantity and figure for many hours: but as the heat declines they gradually melt away; till at length, when the sun has sunk

below the horizon, the ether is unspotted and transparent. The stars shine through the night with undimmed lustre, and the sun rises in the morning in its brightest splendour. The clouds again begin to form, increase to a certain limit, and again vanish with the evening shades.

This gradation of changes, which we so often see repeated in our finest seasons, might, at first, appear to be contrary to our principles; and that precipitations should occur with the increase of temperature, and disappear with its decline, would seem, at first sight, to be diametrically opposite to all our conclusions. But a little consideration will show that these facts confirm our theory. The vapour rises and is condensed; but in its precipitation falls into a warmer air, where it again assumes the elastic form; and as the quantity of evaporation below is exactly equal to supply this process above, the cloud neither augments nor decreases. When the sun declines, the surface of the earth cools more rapidly than the air; evaporation decreases, but the dissolution of the cloud continues. The supply at length totally ceases, and the concrete vapour melts completely away. The morning sun revives the exhalations of the earth, and the process of nimbification again commences, and again undergoes the same series of changes. The fall of the temperature shifts a little the planes of deposition, but scarcely affects the total pressure of the vapour. The deposition of dew (the formation and concomitant circumstances of which have been so successfully analyzed in the elegant Essay of Dr. Wells,) slightly

diminishes the quantity; but the first touch of the sun's rays restores it to the "blue expanse."

When, however, the natural equilibrium has been disturbed, when the temperature of the air has become equalized through various successive strata by the beds of vapour with which they are imbued, the decline of the day will often determine precipitation, and will increase its amount if already established. The result of observation has also shown that a greater amount of rain falls while the sun is below, than while it is above, the horizon.

10. The elasticity of the aqueous atmosphere in the temperate zones, on the surface of the earth, separated from that of the aërial, generally exhibits directly opposite changes to the latter.

As the quantity of vapour increases, it will mostly be found that the barometer falls; and it rises with its decrease. This observation, which is amply confirmed by tracing the lines of each upon a graduated paper, does not apply to the averages of the different seasons, but to the daily fluctuations. This fact, so utterly irreconcileable with the hypothesis which ascribes the rise and fall of the mercurial column to the weight of the aqueous particles, materially confirms that which attributes the fluctuations to the unequal expansion of balancing currents. The prime source of this expansion we have supposed to be the elastic vapour; and in this respect the theory is confirmed by experience.

The least complicated case, perhaps, of periodical rains occurs in the islands which are situated under

the line, in the Indian Ocean. These form to themselves conditions of periodical condensation corresponding to the diurnal influence of the sun, and the daily motions which take place in the air. The heated land-breeze rises in a state of saturation, which the temperature of the cool sea-breeze cannot support, and the consequence is, daily rain throughout the year in some situations, or at particular seasons in others.

11. From the distribution of the aqueous atmosphere which we have already traced over the globe, it might be inferred that the maximum depth of rain ought to be found in the equatorial regions, and that there ought to be a diminution in its quantity from these regions to the poles; and in a general way this will be found to be the case, although we cannot connect either the rain at the same place with its average mean temperature, or trace any relation between the temperature of two geographical parallels and the average precipitation of rain upon them. The following Table of the annual results for ten years, both of the rain and the mean temperature of the Malabar coast, will show the prodigious aberrations which the rain undergoes, while the annual temperature oscillates within very moderate limits.

TABLE LI. *Mean Temperature and annual amount of Rain on the Coast of Malabar.*

Date.	Annual Rain, in inches.	Annual Mean Temp.
1810	125·90	80°·16
1811	104·90	80·13
1812	102·70	80·50
1813	93·85	80·35
1814	115·10	78·56
1815	133·40	——
1816	100·00	78·61
1817	136·70	79·00
1818	169·19	81·00
1819	135·47	80·78
1820	147·18	80·92
1821	98·44	82·25
1822	145·60	81·50
1823	121·67	82·00
Mean . .	123·50	80·04

The results included in the following Table will indicate the decrease of the depth of rain as we travel from the equator towards the north pole.

TABLE LI. *Amount of Rain from the Equator towards the North Pole.*

Places.	Latitude.	Amount of Rain, in inches.
Coast of Malabar	Mean, 11½ N.	123·5
Granada - -	12 N.	126
Cape François -	19·46	120
Calcutta - -	22·23	81
Rome - -	41·54	39
England - -	50° to 55	31
Petersburgh -	59·16	16
Uleaborg - -	65·1	13½

Colonel Sykes observes, that the deluge-like character of a monsoon in the Ghâts of Western India is attested by the annual amount of 302·21 inches, at Malcolmpait, on the Mahabuleshwar Hills*.

But Humboldt fixes the rain at the equator, and in the three following latitudes, as in the succeeding Table.

TABLE LIII. *Corrected amount of annual Rain for the Latitude.*

Latitude.	Mean Annual Rain.
0	96
19	80
45	29
60	17

12. Notwithstanding this progression the number of rainy days is least at the equator and increases in proportion to the distance from it. According to Cotte, the mean number of rainy days increases with the latitude in the following progression.

From 12° to 43° North, the mean number		78
„ 43 to 46	. . . . .	103
„ 46 to 50	. . . . .	134
„ 50 to 60	. . . . .	161

13. The fall of rain, however, on the sea-coast is much more considerable than in places in other respects similarly situated in the interior of different countries. The influence of the western coasts, in

* *British Association, Report*, 1842.

particular, has been already pointed out. It has been calculated that in proceeding from the west inland, the rain decreases one-third in amount. Göttingen, Paris, and Toulouse, not far from the coast, have an average fall of rain amounting to 21·7 inches; whereas, at Prague and Buda, situated in the heart of Europe, and not much elevated above the sea, the annual fall is only 15 inches.

Some extreme cases of rain are upon record, which, but for the respectability of the authorities by whom they have been recorded, would scarcely be credible. Capt. Roussin relates, that 151 inches of rain fell at Cayenne in the month of February; and even in the temperate region of France, M. Arago states, that at Joyeuse, on the 29th October, 1827, there fell in 22 hours only, a depth of 31·173 inches of rain.

The elevation and broken surface of the ground also exert a decided influence upon the mean quantities of rain which fall in the different latitudes, and mountainous countries are in all cases found more humid than those which are comparatively level. This is owing to the deflection, breaking, and mingling of the different winds which rebound from the acclivities, and whirl in eddying currents both in vertical and horizontal directions. The western winds, which, as we have before explained, are the great transporters of the vapour, are often thus broken upon the western sides of a mountainous coast, and being held back in their course, have time to precipitate the moisture which otherwise would by their agency be more widely diffused. In our own country, Keswick and Kendal,

situated amongst mountains, have annual mean amounts of rain 67·5 and 54 inches, while many places in the interior of the country, and even on the eastern coast itself, have only 25 inches.

As examples of a single year, when the places are not far distant from each other, and their elevations known, we may take the following:—

	Height in feet.		Amount of Rain in inches.
Venice	0	„	31·8
Verona	232	„	35·0
Udina	359	„	64·7
Tolmezzo	1535	„	109·2

At Geneva, by a mean of 32 years, the annual fall of rain is 30·7 inches; at the Grand St. Bernard, by a mean of 12 years, it is 60·05.

The mere elevation in the atmosphere is not the cause of this increase, for it has been ascertained that more rain falls at the bottom of a mountain than at the top; and in all situations a greater quantity falls close to the ground than at any height above it. The fact has been placed beyond dispute by the most careful and unexceptionable observations.

14. Messrs. Phillips and Gray, Secretaries of the British Association, made a careful series of observations at York, for the purpose of elucidating the subject, and compared the quantities of rain which fell at a height of 9 feet above the Minster, or 241 feet 10½ inches above high water in the Humber, with those which fell on the top of the Museum and on the level of the ground, which were respectively 72 feet 8 inches, and 29 feet, above the same level.

The totals for 12 months were,—

	Inches.
Minster Gauge	15·910
Museum	20·461
Ground	24·401

and they found the ratios of the quantities for 3 years' observations,

	Inches.
Minster	50·15
Museum	79.14
Ground	100

The whole difference in the quantity of rain at different heights above the surface of the neighbouring ground, Mr. Phillips ascribes with great probability to the continual augmentation of each drop of rain from the commencement to the end of its descent, as it traverses successively the humid strata of air at a temperature so much lower than that of the surrounding medium, as to cause the deposition of moisture upon its surface.

It has been objected to this explanation, that the latent heat given off upon the surface of the drops by this condensation of steam upon them, would soon raise their temperature above that of the dew-point, when of course their augmentation would cease. This effect must certainly be taken into the account; but there is another cause of the increase of the drops falling through a saturated atmosphere, which has not yet been alluded to. Whenever the particles of floating moisture in the form of clouds or fog, or condensing steam, are brought into contact with one another with mechanical force, as when they are carried by the wind against any opposing obstacle, as a tree, a rock, or a

building, they quickly coalesce, become too heavy to be buoyed up by the air, and commence a rapid descent in the form of rain. This is an observation which any one may make, who will attend to the phenomena of those dripping fogs with which our climate is sometimes infested. In the same way drops of rain falling by their gravity through a saturated and precipitating atmosphere, will gradually have their dimensions increased from a mechanical cause, independent of their temperature. Both these causes probably contribute to the observed effect, and it will be remarked that this hypothesis takes account of the length of descent, because in passing through more air more moisture would be gathered; it agrees with the fact, that the augmentation for given lengths of descent is greatest in the most humid seasons of the year; it accounts for the greater absolute size of rain-drops in the hottest months, and near the ground, as compared with those in winter, and on mountains; and finally, it is an almost inevitable consequence of the gradation of temperature in the air, that some effect of this kind should take place. The very common observation of the cooling of the air at the instant of the fall of rain, the fact of small hail or snow whitening the mountains, while the very same precipitations fall as cold rain in the valleys, when the dew-point may be many degrees above freezing, is enough to prove this. A converse proof of the dependence of the quantity of rain at different heights on the state of the air at those heights, is found in the rarer occurrence of a shower falling from a cloud, but dissolving into the air without reaching the ground.

15. Rain also rarely reaches the earth at times when the hygrometer indicates that the dew-point is below the temperature of the air, but a progressive decrease instead of an increase of the drops, must at such times take place, and the usual phenomenon of an increment proportioned to the descent, can only occur in a saturated atmosphere, the natural progression of whose temperature has been destroyed by the latent heat evolved by the precipitation, of which indeed it affords a striking evidence.

The precipitations of vapour in the atmosphere do not always reach the earth in the form of rain, but the particles of moisture, in some stage or other of their descent crystallize, and when the temperature is sufficiently low, fall upon the ground as flakes of snow. The process may be compared to, and exactly resembles, that which is known to chemists by the name of sublimation, in which different bodies, such as camphor, sal ammoniac, &c., rise in vapour, and form crystals without going through the intermediate process of liquefaction. The forms which snow presents, are often of the greatest beauty and regularity, particularly when formed at a very low temperature. We owe to Dr. Scoresby the most accurate delineations of these forms as seen under the microscope; they are so numerous, that he has arranged them under five classes.

The latent heat which is evolved by the condensation of vapour into snow is even greater than that from an equal weight condensed into water, and of course produces the same effect upon the aërial

columns. In consequence of its less density, snow is much longer in reaching the earth, in its fall from the clouds, than rain. All other things being the same, Professor Leslie calculated that a flake of snow, taken as nine times more expanded than water, descends thrice as slow.

16. In the upper regions of the atmosphere the clouds must often consist of frozen particles, even in latitudes where the temperature can never admit of a fall of snow upon the earth. This is in fact proved by their action upon light, which gives rise to the luminous appearance known by the names of *halos* and *parhelia*. These interesting phenomena have been shown to arise from the refraction of light through prismatic crystals of ice descending through the air in all possible directions. They may be artificially imitated by allowing a dilute solution of alum to evaporate spontaneously from a plate of glass. The surface becomes covered with small crystals of the octohedral form; and upon interposing the plate between the eye and any artificial light, an exact representation of the halo is produced. Such phenomena surrounding the sun or moon, if carefully observed, might furnish us with important data regarding the temperature of the higher regions of the air.

17. The phenomena of hail it is much more difficult to account for than the preceding. When of small size, it appears as frozen rain-drops; and if this were all, there would be perhaps no difficulty to ascribing their origin to such drops falling through cold strata of the air, and gradually increasing in size as they fall;

but hail is comparatively rare in winter; and the clouds from which it falls are commonly observed to be of no great altitude. Very frequently in the centre of hailstones small flakes of snow are to be found; and, generally speaking, these are the only opaque parts in them, the concentric strata with which they are surrounded having all the transparency of common ice. Sometimes the hailstones assume the form of transparent convex lenses, of such regularity that they magnify objects without at all distorting them.

Professor Leslie has computed that hailstones sometimes fall with a velocity of 70 feet per second, or at the rate of about 50 miles per hour. Striking the ground with such impetuous force, it is easy to conceive the extensive injury which a hail-shower may occasion in the hotter climates. Authentic instances are upon record of masses of ice having fallen from the atmosphere weighing from 4 to 9 ounces, and of others measuring from 13 to 15 inches in circumference.

It is impossible to account satisfactorily for such phenomena on account of our imperfect knowledge of the influence of a most powerful agent which doubtless is concerned in many meteorological phenomena, namely, electricity.

As a proof of electrical action, it is sufficient to follow for a short time the movements of an atmospherical electrometer, on the approach of hail, when the electricity will not only be found frequently to change in intensity, but also to pass from positive to negative, and *vice versâ*, ten or twelve times in a

minute. Thunder and lightning are, moreover, very common accompaniments of a hail-storm; and it has been remarked that frequently before the descent of hail, a noise is heard—a particular kind of cracking, which it would be difficult to describe in any other way than by comparing it to the emptying of a bag of walnuts.

We purpose to show the lamentable state of our ignorance with regard to atmospheric electricity in a separate paper, not without hopes of stimulating inquiry into a branch of natural science which promises to repay the application of modern resources to its study with the most important results.

Another agency has been passed over in the previous investigation, on account of its comparatively small amount, and the obscurity in which it is involved, which cannot but have some power in modifying atmospheric changes. I allude to the influence of the moon.

That the different phases of the moon have some connexion with changes in the atmosphere, is an opinion so universal and popular, as to be, on that account alone, entitled to attention. No observation is more general; and on no occasion, perhaps, is the almanac so frequently consulted, as in forming conjectures upon the state of the weather. The common remark, however, goes no further than that changes from wet to dry, and from dry to wet, generally happen at the changes of the moon. When to this result of universal experience we add the philosophical reasons for the existence of tides in the aërial ocean,

we cannot doubt that such a connection exists. The subject, however, is involved in much obscurity.

Mr. Howard is the only one who has treated it with the consideration which it deserves. In his book may be found much information upon it, the fruits of laborious investigation; and in the *Philosophical Transactions* for 1841, he has recorded the results of eighteen years' observations in the neighbourhood of London, from which he draws the conclusion that there is a decrease in the barometrical mean, consequent on the moon's varying positions in declination, which may be thus stated: 29·8274 inches on the equator, *minus* by north place ·0116 inches, again *minus* by passage of equator south ·0158 inches; again *minus* by south place ·0189 inches; lastly, *plus* by return north over equator ·0463 inches. This, he thinks, is "evidence of a great *tidal wave* or swell in the atmosphere, caused by the moon's attraction, preceding her in her approach to us, and following slowly as she departs from these latitudes." It would be foreign to my purpose to enter at large upon this interesting ground, but the previous investigation suggests one particular view of it, which it may be useful shortly to state.

The action of the moon upon the aërial columns over which it passes may be regarded as diminishing the force of gravity. This action must be greater in proportion as the moon approaches the earth; in proportion as it coincides with the analogous action of the sun; and in proportion as its passage over the meridian comes near to the perpendicular direction.

The result of this diminution of gravity must be a general decrease of density; and its effect upon the lateral currents, an acceleration of the incoming and a decrease of the outgoing streams. The loss of weight will thus be compensated, and the excess of elasticity hence derived will lengthen the column. The final adjustment will, therefore, be assimilated to that which arises from an equal expansion by heat. Now the effect of the atmospheric tide has hitherto been sought for, and measured upon the surface of the earth, at the base of the column; and much conjecture and disappointment have ensued, from not finding the effect as great, or as regular, as had been anticipated. But, if this view of the subject be correct, the total weight of the perpendicular column would not be affected so much as that of its horizontal sections; and the amount of the lunar influence should be sought in the variations of the differences of density between some high elevation and the level of the sea. The mean of a series of experiments carefully conducted with this view, when the moon is upon the meridian and at the horizon, would possibly exhibit the amount of the daily tides; their weekly increase and diminution; the influence of the moon's apogee and perigee; and that of its north and south declination. It has, however, I think, been proved that the influence is still felt at the surface of the earth; and the barometer, upon an average, stands lower at new and full moon than at the quarters. This also would naturally be expected when it is considered that the attraction of the moon is an action upon the power of gravity, and

acts instantaneously in the perpendicular direction; while the compensating effects upon the lateral currents are gradual.

CONCLUSION.

I HAVE thus traced the outline which I proposed; and I trust that it will be found that I have not wholly failed to elucidate some hitherto obscure points of the history of the atmosphere. It tends to give me some confidence in the justness of my views, that when I first conceived the idea of conducting my researches synthetically, I anticipated but few of the conclusions to which the experiment has led me.

The principles which I have employed are the fruits of the researches of the most eminent philosophers; to have owned my obligations to whom would have loaded this Essay with references. Their labours are become the foundation-stones of science, and the common property of those who may follow them in endeavours to perfect the edifice.

I have scrupulously adhered to the natural consequences of the premises which I have adopted, without previously inquiring how far they were consonant with the phenomena to be explained: in their after application to these phenomena, I hope that it will be found that I have not been unsuccessful. The fluctuations of the barometer, and most of the phenomena of wind and rain, appear to me to adapt themselves most happily to the theoretical conclusions.

Both the *synthetical* and *analytical* processes agree in the same grand conclusions, which may thus briefly be recapitulated:

There are two distinct atmospheres, mechanically mixed, surrounding the earth; whose relations to heat are different, and whose states of equilibrium, considering them as enveloping a sphere of unequal temperature, are incompatible with each other. The first is a permanently-elastic fluid, expansible in an arithmetical progression by equal increments of heat, decreasing in density and temperature according to fixed ratios, as it recedes from the surface, and whose equipoise under such circumstances, would be maintained by a regular system of antagonist currents. The second is an elastic fluid, condensible by cold with evolution of caloric; increasing in force in geometrical progression with equal augmentations of temperature; permeating the former and moving in its interstices, as a spring of water flows through a sand-rock. When in a state of motion this intestine filtration is retarded by the *inertia* of the gaseous medium, as it is promoted by its various movements; but in a state of rest the particles press only upon those of their own kind. The density and temperature of this fluid have a tendency likewise to decrease, as its distance from the surface augments; but by a less rapid rate than that of the former. Its equipoise would be maintained by the adaptation of the upper parts of the medium, in which it moves, to the progression of its temperature, and by a current flowing from the hotter parts of the globe to the colder.

Constant evaporation on the line of greatest heat and unceasing precipitation at every other situation, would be the necessary accompaniments of this balance. Now the conditions of these two states of equilibrium, to which, by the laws of hydrostatics, each fluid must be perpetually pressing, are essentially opposed to each other. The vapour or condensible elastic fluid is forced to ascend in a medium, whose heat decreases much more rapidly than its own natural rate; and it is therefore condensed and precipitated in the upper regions. Its latent caloric is evolved by the condensation, and communicated to the air; and it thus tends to equalize the temperature of the medium in which it moves, and to constrain it to its own law. This process must evidently disturb the equilibrium of the permanently-elastic fluid, by interfering with that definite state of temperature and density which is essential to its maintenance. The system of currents is unequally affected by the unequal expansion; and the irregularity is extended, by their influence, much beyond the sphere of the primary disturbance. The decrease of this elasticity above, is accompanied by an extremely important re-action upon the body of vapour itself; being forced to accommodate itself to the circumstances of the medium in which it moves, its own law of density can only be maintained by a corresponding decrease of force below the point of condensation; so that the temperature of the air, in its normal state, at the surface of the globe, is far from the term of saturation; and the current of vapour, which moves from the hottest to the coldest

points, penetrates from the equator to the poles, without producing that condensation in mass, which would otherwise cloud the whole depth of the atmosphere with precipitating moisture. The clouds are thereby confined to parallel horizontal planes, with intermediate clear spaces, and thus arranged are offered to the influence of the sun, which dissipates their accumulations and greatly extends the expansive power of the elastic vapour. The power of each fluid being in proportion to its elasticity, that of the vapour compared with the air, can seldom exceed 1 : 30: so that the general character of the mixed atmosphere is derived from the latter; which, in its irresistible motions, must hurry the former along with it. The influence, however, of the vapour upon the air, though slower in its action, is sure in its effects, and the gradual and silent processes of evaporation and precipitation govern the boisterous power of the winds. By the irresistible force of expansion unequally applied, they give rise to undulations in the elastic fluid; the returning waves dissipate the local influence, and the accumulated effect is annihilated, again to be reproduced.

In tracing the harmonious results of such apparently discordant operations, it is impossible not to pause, to offer up a humble tribute of admiration of the designs of a beneficent Providence, thus imperfectly developed in a department of creation where they have been supposed to be most obscure. By an invisible, but ever active, agency, the waters of the deep are raised into the air, whence their distribution

follows, as it were by measure and weight, in proportion to the beneficial effects which they are calculated to produce. By gradual, but almost insensible, expansions the equipoised currents of the atmosphere are disturbed, the stormy winds arise, and the waves of the sea are lifted up; and that stagnation of air and water is prevented, which would be fatal to animal existence. But the force which operates, is calculated and proportioned; the very agent which causes the disturbance bears with it a self-controlling power; and the storm, as it vents its force, is itself setting the bounds of its own fury.

The complicated and beautiful contrivances, by which the waters are collected "above the firmament," and are at the same time "divided from the waters which are below the firmament," are inferior to none of those adaptations of INFINITE WISDOM which are perpetually striking the inquiring mind in the animal and vegetable kingdoms. Had it not been for this nice adjustment of conflicting elements, the clouds and concrete vapours of the sky would have reached from the surface of the earth to the remotest heavens; and the vivifying rays of the sun would never have been able to penetrate through the dense mists of perpetual precipitation.

The singular exception to a general law, by which it has been provided that the density of water should decrease with every decrease of temperature below the 40th degree of Fahrenheit, by which warmth is stored up in the bottoms of deep lakes for the use of the subaqueous vegetable and animal creations, has

often been dwelt upon with admiration; but let us turn our attention for a moment to the no less beneficial purpose which is effected by the law of the increase of the specific heat of air with its rarefaction. By the constitution of the atmosphere hence arising the air absorbs its own free heat as it rises from the surface of the earth. Its heat is thus economised and preserved; for if, instead of thus being absorbed and laid up in store, it had remained free, it would have soon become dissipated and lost by radiation, and the influence of another sun would not probably have compensated the waste.

It is foreign to my present purpose to enlarge upon the Power, Wisdom, and Goodness of God, as manifested in the creation of the atmosphere; a subject full of interest, which has been already most ably illustrated in the *Bridgewater Treatises* of Dr. Prout and Professor Whewell; but it never can be beside the purpose to show that as we extend our acquaintance with the different departments of nature, so the proofs of the most exquisite and perfect design multiply; and thus to manifest to the best of our most humble ability, that the Great Creator is not only wise, but "in Wisdom Infinite."

ON THE TRADE WINDS:

CONSIDERED

WITH REFERENCE TO MR. DANIELL'S THEORY OF THE CONSTITUTION OF THE ATMOSPHERE.

IN A LETTER FROM CAPTAIN BASIL HALL, R.N., F.R.S.

Edinburgh,
MY DEAR SIR, *19th January,* 1827.

As you wished to have in writing the substance of my remarks during our last conversation, I have thrown them together for you in the following letter; and, though they go but a short way to exhaust the subject, I trust they may be of use to you in your very interesting speculations on meteorology.

Many persons have a very distinct, but, as I conceive, a very erroneous conception of the Trade Winds. This idea, which has been acquired at school, subsequent reading will probably have tended to confirm; it is, that in north latitude these winds blow always exactly from N.E., and in south latitude exactly from S.E. Some people, again, have merely a vague recollection that the Trades blow from the eastward: while very few persons, probably, are fully aware of the real state of the fact; and it was this belief which induced me to bring the subject to your notice. It is true that there is hardly anything stated here which is not somewhere or other adverted to in your Essays, either

directly, or by implication; but still I conceive your general doctrines may receive support from the practical illustrations which professional occupations have thrown me in the way of observing.

Professional men, as you well know, are so apt to overrate the importance of their own topic, that I hope you will indulge me with a little rope, in my endeavours to explain one of the most curious, and, at the same time, practically useful phenomena in nature. On the other hand, I am so well aware that it is often difficult for readers to understand subjects which lie much out of the ordinary line of their thoughts, that I shall endeavour to render the whole as simple as possible; indeed, my only fear is, that I may be accused of being too elementary.

It is a remarkable circumstance in the history of meteorology, that some of the highest authorities should assign a totally erroneous direction to these winds. I may instance, in particular, the Chart given in Dr. Young's *Natural Philosophy*, where some of the most striking facts of the case are altogether misstated. On the other hand, it is curious enough that the best account not only of the trades, but of every other wind, is to be found in the works of Dampier, under the express head of an Essay on Winds and Currents. Undoubtedly, the facts which he has so skilfully arranged, might be picked out of the works of Cook and other voyagers; but Dampier, whose means were, beyond all comparison, less than were enjoyed by his successors, had the merit of condensing and separating his information in such a way, as not

only to render it available to practical men, but, from the simplicity of the composition to make his writings agreeable to every class of readers. To persons, therefore, who wish a more detailed account of the different tropical winds than I can give you here, I can recommend nothing more satisfactory than the Essay alluded to by this prince of all voyagers, though published more than a century ago.

In modern times, by far the most extensive and exact account of the winds, especially of those blowing between the tropics, is contained in Horsburgh's book of *East India Directions*,—the most valuable gift, perhaps, which well-directed industry has bestowed upon modern navigation. I may be excused, I hope, for using these strong terms, when I mention, that under the sole guidance of this volume, I have sailed over more than a hundred thousand miles of the earth's surface,—sometimes in the dark,—sometimes in stormy weather,—and frequently when not a single soul on board had ever visited the spot. Yet in proportion as my local knowledge became matured, and I could judge of the subject from what I had actually seen, the more unlimited my confidence became in the authority of this admirable navigator.

The only general assertion that can be made with respect to the trade winds, as far as their direction is concerned, is, that they blow more or less from the east towards the west. Even this, however, is not universally true. Neither are they alike on both sides of the equator; nor do they exhibit the same aspect, at different seasons of the year, on the same spot.

I shall first glance at the received ideas upon the subject, and then describe the actual state of the facts as I have observed them; after which, I shall endeavour to give the laws, which regulate these singular phenomena, a place in your imagination, by a theoretical consideration of their cause.

I may mention that these views having suggested themselves to my mind before I met with your book, I had intended to publish some notice respecting them: on seeing, however, the complete manner in which you had exhausted the subject, I abandoned my intention; and I only resume it now, as you seem to think the corroboration of a practical man's opinions may help to substantiate the truths which your sagacity and industry have deduced theoretically.

A few words will serve to describe the common notions upon the subject.—The north-east trade wind is conceived to blow from the exact north-east point, nearly to the equator, when it takes a graceful bend, and blows more and more from the east point, till at length it becomes parallel to it; that is, blows from due east. The south-east trade, in like manner, is supposed to blow at first precisely at south-east, or at an angle of 45° with the meridian, and at last to assume an exact parallelism with the equinoctial line*. This, however, is altogether erroneous. The real state of things is as follows. The trade winds in the Atlantic and Pacific Ocean extend to about twenty-eight degrees of latitude on each side of the

* See the Chart in Dr. Young's *Natural Philosophy*.

equator, sometimes a degree or two farther; so that a ship, after passing the latitude of thirty degrees, may expect every day to enter them. It will, perhaps, assist the apprehension of the subject, to suppose ourselves actually making a voyage to the Cape, first outwards, and then homewards; by which means we shall have to cross each of these winds twice.

Shortly after leaving Madeira, which is in 32½°, we get into the trades, and instead of finding the wind blowing from N.E., as the accounts would lead us to suppose, we shall find it blowing from E., or even sometimes a little southerly. You are seaman enough to be aware that, with the wind at E., a south course can readily be steered, first towards the Canaries, and then to the Cape de Verd islands. It is the most approved practice, I think, to pass just within sight of these islands to the westward of them: that is to say, leaving them on the left hand. As the ship advances to the southward, she finds the trade wind drawing round gradually from E. to N.E., and finally to N.N.E.; and even N., at the southern verge of the north-east trade. This last-named or northern direction, it will be observed, is at right angles to that usually assigned to it—due E., near the line. The southern limit to the north-east trade wind varies with the season of the year, reaching at one time to within three or four degrees of north latitude, and at other times, not approaching it nearer than ten or twelve degrees; but it never crosses the equator and enters the southern latitudes. It will aid the memory in this matter, to bear in mind that the

line, which limits or marks the termination of this trade wind, follows the sun. In July and August it recedes from the equator, in pursuit, as it were, of the sun; while in December and January, when the sun has high southern declination, it reaches almost to the line.

The great difficulty of the outward-bound voyage commences after the ship is deserted by the north-east trade, as she has then to fight across a considerable range of calms, and of what are called the "variables," where the wind has generally more or less southing in it. At certain seasons it blows freshly from the S.S.W., and greatly perplexes the young navigator, who, from trusting to published accounts, expects to find the wind, not from S. but from E. This troublesome range varies in width from 150 to 550 miles; is widest in September, and narrowest in December or January. I speak now of what takes place in the Atlantic; for it is not quite the same far at sea in the Pacific Ocean, where fewer modifying circumstances interfere with the regular course of the phenomena, than in the comparatively narrow neck formed by the protuberances of Africa and South America.

I may remark in passing, that it is upon a knowledge of these deviations from the general rule, which we are pleased to call *irregularities*, that much of the success of tropical navigation depends. A seaman, who trusts to theory alone, will, in all probability, make a bad passage; while another, who relies solely upon past experience, will probably, if the season happens to be different, do quite as badly. The judicious navigator

will endeavour to unite the two; and having attentively studied the theory of his subject, and sought to reduce every case to its principles, checking these from time to time by fresh experience, may be able, when occasions arrive where his own knowledge or that of others entirely fails him, to take that course which, all things considered, is most likely to serve the purpose he has in view.

I knew an officer who was ordered to cruize in the Mozambique channel, between Africa and Madagascar, until a certain day, and then to proceed to the Isle of France. At the time appointed he sailed to the northward; but, though he proceeded nearly to the Line in search of a north-west wind, he could not make a bit of easting; and, after six weeks of ineffectual struggle between the north end of Madagascar and the equator, he was obliged, for want of water, to run for a port in Africa, where he lost the half of his crew by sickness, and was compelled to bear up at last for the Cape of Good Hope, and the whole object of his mission was defeated. Unfortunately, while he knew nothing of the theory of these subjects, he had heard, in a general way, that north-westerly winds occasionally blew in that quarter, between the trade winds and the equator. He was right, indeed, as to the fact, but wrong as to the season. A very slight knowledge, however, of the principles which regulate the winds, might have taught him that the *irregularity*, of which he hoped to take advantage, would probably not have occurred at that particular season, and that he ought to have gone, not to the north, but, in the opposite direction, to the

southward, where he would certainly have found a fair wind. Had he done so, a fortnight or three weeks would have placed him in the port he wished to reach.

But I am forgetting our voyager. We had reached that spot where the north-east trade wind left us rolling about in a dead calm, or with only an occasional violent squall, accompanied by deluges of rain, in a climate so hot that the slightest cat's paw of wind is hailed with the utmost delight. In process of time, the ship, by taking advantage of every such puff of wind, gets across this troublesome stage of her journey, and meets the south-east trade. It is very material to remark that this wind does not blow from the E., as the navigator is led to expect, or in a direction parallel to the equator, and which would be to him a fair wind; but it meets him, as it is emphatically termed, *smack in the teeth.* Instead, therefore, of steering away S., or S.S.E., for the Cape of Good Hope, he is obliged to keep his wind as closely as possible, and he may think himself fortunate, in a dull sailer, if he can clear the coast of Brazil without making a tack. As he proceeds on, however, the wind gradually hauls to the S.E., then to the E.S.E., and at last E., at the southern limit of the trade winds properly so called. Here, after a little baffling weather, he is almost certain of finding westerly winds, which prevail in the latitudes beyond the trades in both hemispheres.

Such are the phenomena most generally observed with respect to the regular trade winds outward-bound. We shall now, in order to make things quite clear, in-

vert the order of the voyage, and suppose the ship, after having reached the Cape of Good Hope, to turn back again. At first she may be plagued with westerly and north-westerly winds; but she will generally be able to stretch into the trades, where she will at first find the wind hanging far to the E., and it may even have some northing in it at first. As she proceeds onwards to St. Helena, which lies directly in the track of homeward-bound ships, the wind will draw to the E.,—E.S.E.,—S.E., and eventually, to S.S.E. At crossing the equator, it will probably be blowing from due S., and not (I must again beg you to take particular notice) from due E., as we are generally led to suppose. After reaching 3° or 4° of north latitude, the ship will lose the south-east trade, and re-enter the "variables," where, when it is not calm, she will generally find light southerly winds, and, at one period of the year, namely, about July and August, blowing briskly from the S.W., as far as 10° or 12° of north latitude. At other seasons, especially when the sun is near the line, a ship may expect light winds from all quarters of the compass, long calms, and now and then a furious squall, with deluges of rain. But at every season of the year, the homeward-bound passage, or that from the southward, is much easier made than the reverse.

On reaching the southern limit of the north-east trade wind, the seaman finds the wind blowing in his face from the N., (exactly as he formerly met the south-east trade, blowing, not from E., but from the south pole,) and is obliged to stretch away to the W.N.W. at

first, and then N.W., as if he were going to the United States of America—not to Europe. As he sails on, and gets more into the trade, it draws round gradually to N.E. and E.N.E., which allows of his "coming up" more and more every day, till at length he can steer N., and even N.E.; so that he is enabled frequently to "look up" for the Azores or Western Islands. By-and-by he bids adieu to the north-east trade, in about 28° or 29° of north latitude, as he formerly did of the other trade, in the correspondent degree south. In like manner, also, he will now almost always meet with westerly winds, which will carry him to the Channel. It may be remarked by the way, that these westerly winds are not so regular as they are in the southern hemisphere, owing probably to the comparative absence of land, which enables the general principle, by which the winds are produced, to act there with greater uniformity*.

If these descriptions have been rendered sufficiently intelligible to a person who has not before

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* The number of days required by the packets between Liverpool and New York, to make the passage outwards and homewards, places this in a striking point of view:

The average of the whole of the passages made by the packets in six years, from Liverpool to New York, that is, from east to west, is	40 days.
The average, during the same period, of the same vessels from New York to Liverpool, or from west to east, is	23 days.

—See HODGSON'S *Letters on North America*, vol. ii. p. 345.

considered the subject, I think he will be in a situation to comprehend the theory; and when that is duly fixed in his imagination, he will find it useful to go back again to the facts stated above, with sharper powers of observation, and a judgment more fitted to arrange and generalize these materials to good purpose. To persons, indeed, already acquainted with your admirable *Meteorological Essays*, much of what follows will appear superfluous; but I prefer giving my own views, without reference to your book, (which I had not seen at the time I conceived the following explanations,) in order to keep up the connexion between my experience and the theory actually suggested thereby at the time.

It may be right to state, however, that I by no means pretend to assert that these ideas have any claim to originality; for there are some treatises in which parts of the theory are to be found, though I am not acquainted with any work antecedent to yours, which accounts for the direction and force of the winds on principles applicable to practice.

The most elaborate work I am acquainted with on these subjects, is Col. Capper's *Observations on the Winds and Monsoons*, printed in 1801. But he never once, as it appears to me, throughout his work, assigns the right cause for the phenomena, which, in most cases, he describes extremely well. Dr. Halley's theory of the wind following the course of the sun in his diurnal motion to the west, (which Col. Capper quotes,) is equally unsatisfactory. In describing the trade winds of the Atlantic, Col. Capper errs essen-

tially in several particulars, especially where he says* that the north-east perennial extends sometimes to four or five degrees south of the equator, which I believe it never does.

If air at any particular spot be heated, it becomes specifically lighter than the adjacent cooler parts, and consequently rises; while its place is speedily occupied by the contiguous less rarefied or colder air. Now, the region of the globe lying between the tropics, or, we may say, between thirty degrees on each side of the equator, being exposed to the most direct rays of the sun, becomes heated; and the air in contact with this belt, or zone, becoming rarefied, rises with more or less rapidity, according to the circumstances under which the earth is situated. Where an open ocean is found, the incumbent air will be less heated, as in the Pacific, than where districts of dry earth are found, as in Mexico for instance. The partial vacuum thus formed will, in both hemispheres, be supplied by the adjacent air lying, we shall suppose, between the latitudes of thirty and fifty degrees. If this be admitted, most of the phenomena of the trade winds will, I conceive, be readily explained. It must be granted, however, before proceeding farther, that a volume of air put into motion is, like every other body, possessed with a momentum, which will continue that motion till stopped by its friction against the fluid through which it is propelled, or by that of the surface of a solid body along which it may be

* CAPPER, page 36.

impelled. Any one who has observed the ring of smoke sometimes projected from the mouth of a cannon will understand this; or the familiar experiment of blowing out a candle by means of the air forced from an uncharged gun, by means of one of the copper priming caps, affords ample illustration that a mass of air once put in motion, will retain that motion like any other portion of matter.

The velocity of the earth's rotation at the equator is, in round numbers, 1000 miles an hour; at latitude 30° it is about 860, or about 140 miles an hour slower. The average velocity of the earth's easterly motion, in the space between the equator and latitude 30°, may be stated at 950 miles an hour; while that of the belt lying between 30° and 40° is not much above 800 miles an hour*.

The superincumbent air at these places respectively, *supposing no difference of temperature to exist*, would of course partake of the earth's velocity, and there would be a universal calm. But, if we sup-

* If the equator be supposed to move at the rate of 1000 miles an hour, the different parallels of latitude will move at the following rates, which are to 1000, as the cosine of the latitude to radius.

Latitude.	Velocity per Hour.	Latitude.	Velocity per Hour.
0°	1000	50°	643
10	985	60	500
20	940	70	342
30	866	80	174
40	766	90	0

pose the tropical region to be heated, the air over it will instantly ascend, and take its station above the cold; while the colder and more dense air lying beyond the tropics will rush in to occupy its place, below that which has been heated. This hardly needs illustration; but,' as I have more than once met with people who did not immediately see the consequences which follow from placing two fluids of different density side by side, I may suggest the experiment of a trough, divided by a sluice in the centre into two spaces, one of which may be filled with water, the other with quicksilver: both fluids will of course be at rest until the sluice be drawn up, when the heavier fluid will instantly rush in beneath the lighter, and the lighter will flow along above the quicksilver. If, instead of these fluids, we substitute hot and cold water, the same thing will take place, the cold always flowing under the hot, towards the place formerly occupied by the lower strata of the heated fluid; while the heated portion flows along over the cold, towards the place formerly occupied by the upper strata of the cold fluid. Exactly the same thing will take place if two portions of air, at different temperatures, be the contiguous fluids; though the phenomena will not now strike the senses so strongly.

It would not be difficult, I conceive, to have a globe fitted with a contrivance which should represent the operation of the trade winds; and perhaps a description of such an apparatus will be as ready a method as any other of explaining my views of this theory. Having taken a common globe, I would in-

close its tropical region from thirty degrees north to thirty degrees south, in a glass zone or coating concentric with the globe, and also each of the belts lying between the latitudes of thirty and fifty degrees in like manner, with distinct cases placed respectively in close contact with the tropical glass coating, and divided from it by partitions removeable at pleasure; I would fill the tropical case with hot water, and the middle latitude cases, or those embracing the space contained between the latitudes of thirty and fifty degrees in both hemispheres, with cold water; or, which would represent the actual fact still better, a broad ring of heated iron might be fixed round the equator to represent the torrid zone, while the middle or temperate latitudes, both north and south, should be encircled with rings of ice. The water might also be coloured, in order to render the effects visible. Things being arranged as above described, and the globe being supposed *for the present* at rest, if the division between the hot and the cold fluids were removed, the cold water would gradually slide along *under* the hot towards the equator, while the heated water would be carried *over* the cold towards the poles; and, if nothing else were done, that is to say, if the globe were allowed to remain at rest, a mere circular interchange would take place. The temperate portions of the fluid, on coming into contact with the torrid zone of the globe, and being thereby heated and rendered specifically lighter, would necessarily rise; while the hot portion, on flowing towards the cooling substance in latitudes farther from the equa-

tor, would descend to occupy the place of the cold water drawn off to supply the place of the lighter heated water at the equator. A steady current would in this way be produced, running below towards the equator, and at right angles to it, and above towards the poles; this would evidently be the only motion impressed on the fluid as long as the globe stood still.

It is material to remark here, that this motion would be less and less obvious as the currents approached the equator, where the cold fluid would gradually become heated, and have a tendency to rise as well as to flow along, so that their course would be checked, till at length, at the equator, the opposite currents would meet and produce a calm.

While things are supposed to be in this situation, let the globe be put into rapid motion from west to east, we shall say, for the sake of illustration, at the rate of one thousand feet in a minute, while all the circumstances as to temperature remain as before. The cold water would continue to flow just as before, under the hot, towards the equator, where the rarefying cause existed, but it would now come to the equatorial regions, possessed, not only with a motion directly towards the equator, but with the easterly velocity due to that circle of latitude which it had left, or about eight hundred feet in a minute; and if we suppose these equatorial regions to be moving to the eastward at the average rate of nine hundred and fifty feet in the same interval, the cold water moving at the slower rate would inevitably at its first arrival

there be left behind; or, which is the same thing, the surface of the globe would go faster to the eastward than the superincumbent water, and this, in effect, would produce an apparent or relative motion of the water from east to west; or, if the fluid in question were air, we should there have what we call an easterly wind.

This, in its most general sense, is what really takes place with the trade winds, and, if what I have said be well understood, all the modifications which they undergo will be readily seen to follow.

The cold air, however, (it must be carefully observed,) which comes towards the equator, is acted upon by two forces, or, in other words, is influenced by two sources of motion; first, by that which has been impressed upon it, in a due easterly direction, by the rotation of the earth in the temperate latitudes it has left; and, secondly, by a motion, in the direction of the meridian, towards the equator, and at right angles to it. This last is caused by the air rushing in to fill up the space left by that which has been rarefied by the heat of the torrid zone, as shown in the first experiment, where the globe stood still; in which case, it will be remembered, this was the only motion to which the fluid was exposed. The combined effect of these two motions is to produce the south-east trade wind in south latitude, and the north-east trade on the other side of the equator.

When the comparatively slow-moving air of the temperate zone, caused by the rotatory motion of the earth to the east, first comes into contact with the

quick-moving or tropical belt of the globe, the difference of their velocities is great compared with the other motion of the air above described, or that directly towards the equator; and consequently the wind blows at the extreme edge of the trades nearly from the east point. As this cool air, however, is drawn nearer to the equator, and comes successively in contact with parallels of latitude moving faster and faster, this constant action of the earth's rapid easterly motion gradually imparts to the superincumbent air the rotatory velocity due to the equatorial regions which it has now reached; that is to say, there will be less and less difference at every moment between the easterly motion of the earth and the easterly motion of the air in question; while, at the same time, the other motion of the same air, or that which has a tendency to carry it straight towards the equator, having been exposed merely to the friction along the surface without meeting any such powerful counteracting influence as the earth's rotation, will remain nearly unchecked in its velocity. Thus, as I conceive, the trade wind must gradually lose the eastern character which it had on first quitting the temperate for the tropical region, in consequence of its acquiring more and more that of the rotatory motion of the earth due to the equatorial regions it has now reached. While this cause operates, therefore, to destroy the easterly direction of the trades, the meridional motion, as it may be called, or that towards the equator, by remaining constant or nearly so, will become more and more apparent, till at length, when the friction of the

earth in its rotatory motion has reduced the velocity of the cool air to the tropical rate, there will be left only this motion towards the equator, which is found invariably to characterize the equatorial limits of both trade winds. This velocity, also, is at length checked, first, by its friction on the surface of the earth; secondly, by the air becoming heated, which causes it rather to rise than to flow along the surface; and thirdly, by the meeting of the two opposite currents — one from the north, the other from the south.

In confirmation of these doctrines, I may state that, in the trade winds, the higher clouds are very seldom, if ever, observed to go in the same direction as the wind below. In general they are seen to move nearly in the contrary direction; and I find it noted in my journal, that on the top of the peak of Teneriffe, the wind was blowing from the S.W. directly in the opposite direction to the trade wind below.

In what has been said above, the quickest-moving or equatorial belt of the earth is assumed as being also the hottest, and consequently that over which the air has the greatest tendency to rise. This, however, is not the case universally; and where variations in this respect occur, effects very different from those described are the result. The most striking examples, with which I am personally acquainted, of this deviation from the general law of the trade winds, or that which would obtain, were the earth a uniform mass of water, or land, occur in India and Mexico. That portion of the Pacific Ocean, which stretches from the

Isthmus of Panama to the Peninsula of California, lies between eight and twenty-two degrees of north latitude. Now, the sun's rays strike directly upon the adjacent great territory of Mexico, and, by heating the land violently, cause the air to rise over it. But the vacuum is filled up not only from the northward, but by the comparatively cold air of the equatorial regions in the neighbourhood. The air coming from that part of the globe which revolves quickest, to one which moves more slowly, produces not an easterly, but westerly and south-westerly winds; so that the navigator, who works by what is called the rule of thumb, and takes things for granted, instead of inquiring into them, will be very apt to make sad blunders in his navigation. I confess that I once laid myself open to an accusation little short of this, for which I had less excuse, perhaps, than another man, since, from having long speculated upon these topics, I had in a great measure satisfied myself of the truth of these theories. Yet when I was sent to visit the south-west coast of Mexico alluded to, and was left to my own choice as to the manner of performing the voyage, I miscalculated the probable effect of so vast a heater as Mexico, and expected to find the winds from E. or N.E.; and therefore begun my voyage at Panama. I soon learned, however, to my cost, that instead of being to windward of my port, I was dead to leeward of it, and I had to beat against westerly winds for many weeks.

After all, however, it is by this union of theory and experience, (which is not the worse for being

dearly bought,) that effectual knowledge can be obtained; and the disasters into which we are led by ignorance must be serious indeed, if they be not more essentially profitable, than mere unobservant success would have been. I mean that our finding things as we expected them is not always a proof that we have reasoned correctly,—for had I visited this coast at another season of the year, and found an east wind blowing, I might have called it the north-east trade, perhaps, and brought away none of the local knowledge, which is now, I trust, well engraved on my mind by the laborious process of rectifying my original error.

The monsoons in India, in like manner, are striking illustrations of this modified part of the theory. When the sun has great northern declination, the Peninsula of Hindostan, the north of India, and China, being heated, the quick-moving equatorial air rushes to the northward to fill up the slow-moving rarefied space, and this supply being possessed not only with a rapid eastern velocity, but with a motion from the south, produces the south-west monsoon in the Indian Ocean, Bay of Bengal, and in the China Sea. When the sun, on the other hand, goes to the S., the same seas are occupied by air which, coming from regions beyond the northern tropic, possesses less easterly velocity than the space they are drawn to, which gives them an easterly character; and this, combined with their proper motion, if I may so call it, from the N., produces the north-east monsoon.

There are numberless other less striking modifica-

tions of these principles, which give a high degree of interest to the science of navigation, particularly between the tropics; but which it is needless to enter into just now. It may, however, be useful to mention one important case which occurs in the Atlantic, when the sun has high northern declination, and the north of Africa is much heated; the equatorial air is then invited to the N., and a brisk south-west or south-south-west wind blows in the space between the equator and the southern limit of the north-east trade wind, which lies then in ten or twelve degrees of latitude, greatly to the astonishment of the inexperienced navigator, who, trusting to his books, expects a wind directly the reverse.

The same reasoning, precisely, will serve to account not only for the direction but for the degree of strength with which the winds blow between the trades and the polar regions—that is, from 30° to 60°. The heated air which rises over the tropical belt is carried towards the poles till it is sufficiently cooled, when it descends, and, by encountering a part of the globe going to the eastward at a much slower rate, produces westerly winds. It must be observed also that, as the lower or cold air of this range proceeds towards the equator, it encounters, at every stage of its course along the surface, parallels of latitude moving faster and faster to the eastward, and consequently is exposed to more and more friction, by which means the relative difference between its velocity and that of the earth becomes at every moment less and less, till it subsides at length into a calm. But the

equatorial air, on the contrary, in its progress towards the middle latitudes, comes constantly to regions of the globe moving with less and less velocity, so that it descends from the high regions of the atmosphere, along which it has passed with less friction to check its easterly motion than the lower or cold current must have had to contend with, in its passage along the earth's surface. This equatorial air, therefore, comes, with scarcely any diminution of its original velocity, into contact with a part of the earth moving more than a hundred miles more slowly to the eastward than itself. Consequently we have furious westerly gales as far as Madeira, on the one side, and the Cape of Good Hope on the other, which lie just beyond the north-east and south-east trade winds, in the opposite hemispheres.

There are many other modifications of this theory of the winds with which it is not at present my purpose to trouble you, but I may mention, before closing my letter, that I do not remember to have met with a single circumstance connected with the winds, in any part of the globe, that, when I succeeded in understanding it, was inconsistent with those philosophical reasonings which you have the undoubted honour of having first brought distinctly before the public.

I remain, my dear Sir,

Most truly yours,

Basil Hall.

To J. F. Daniell, Esq.

ADDITIONAL REMARKS

UPON THE

OSCILLATIONS OF THE BAROMETER.

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§ 1. ON THE HORARY OSCILLATIONS.

THE Horary Oscillations of the Barometer constitute a class of phenomena of the highest interest to meteorology. Their origin has always been deemed extremely obscure, but their regularity and wide extension over the surface of the earth have generally excited a hope that they would ultimately afford the key to the solution of the problem of the greater fluctuations of the aërial ocean, which the invention of Torricelli detected. I am not, however, aware that any attempt has ever been made to account for them previous to the hints which I ventured to throw out upon the subject in the first edition of these Essays. Since that period (1823), much reflection on the subject has convinced me that the fundamental conception of that explanation is correct, and has enabled me to state it, I trust, with more precision in the preceding pages. The phenomena, however, require, and indeed, are receiving daily, much more careful examination, and as I could not well pursue the matter further in the preceding Essay without an extension which would have been disproportionate to its other parts, I have

thrown together the following observations in the form of an Appendix. Indeed, the history of the subject, recent as it is, requires a few observations on my part.

The barometric column was first observed to have a daily periodical vibration between the tropics, by the expedition under the command of the unfortunate La Peyrouse. M. Lamanon, the naturalist, has given an account of these observations in the second volume of the voyage, at page 521. He states that from about the 11th degree of north latitude, he began to perceive a certain regularity of motion in the barometer, so that the mercury stood highest about the middle of the day, from which time it descended till the evening, and rose again during the night. As they approached the equator, the effect became more distinct, and on the 28th September (1785) a series of experiments were begun in 1° 17′ north latitude, and continued for every hour, till the 1st of October. The following are the results of the observations on the 28th and 29th.

Sept. 28.	From 4 to 10 A.M., barometer rose	0·19 inch.
	From 10 A.M., to 4 P.M.	fell 0·12
	From 4 to 10 P.M.	rose 0·09
Sept. 29.	From 10 (28th) to 4 A.M.	fell 0·13
	From 4 to 10 A.M.	rose 0·15
	From 10 A.M. to 4 P.M.	fell 0·13
	From 4 to 10 P.M.	rose 0.10

The observations on the 30th were to the same effect.

Hence it was inferred that there is a periodical flux and reflux of the atmosphere, at the equator, pro-

ducing in the barometer a variation of about 0·12 inch (English), corresponding, according to M. Lamanon, to a height in the atmosphere of about 100 feet. The latitude of the ship on the 28th, was 0° 50′ north; and 0° 11′ north, on the 29th.

In the year 1794, Dr. Balfour published, in the *Asiatic Researches*, an account of some observations made at Calcutta, which agreed in a remarkable manner in the same conclusion. During one whole month, he observed the barometer every half hour: the mercury constantly fell from 10 at night to 6 in the morning; from 6 to 10 in the morning it rose; from 10 in the morning, to 6 at night, it fell again; and lastly, rose from 6 to 10 at night. The *maximum* height was therefore at 10 P.M., and 10 A.M., and the *minimum* at 6 P.M., and 6 A.M. The oscillations sometimes amounted to 0·1 inch, but in general were considerably less.

The observations of the Baron de Humboldt, of Colonel Sabine, and other observers, of a later date, confirm the existence of these semi-diurnal variations in the torrid zone, and extend them to the south of the equator. According to Humboldt's results, the barometer generally falls from 10 o'clock A.M. till 4 P.M.; then rises again till 10 P.M.—again falls till 4 A.M., and rises till 10 A.M.

It is not, however, in tropical latitudes alone, that these horary motions of the barometer may be detected: the absence of those disturbing causes which affect the atmosphere in temperate climates, and produce the much more considerable but irregular fluctu-

ations of the mercurial column, render them more prominent in those situations; but by a system of averages, which balances the irregularities, the regular movement is elicited, even when most concealed. M. Ramond found at Clermont-Ferrand, in latitude 45° 47′, that a mean of ten days sufficiently neutralized the irregular oscillations, and the periodical motions were distinctly exhibited in intervals of that length. The hours of the fluctuations were, as nearly as possible, coincident with those at the equator; but the effect was considerably less, and did not amount to more than 0·039 inch. The monthly means of the observations made at the Observatory at Paris, present the same result, with a still further reduction of the effect; the average of six years' observations being ·028 inch: and, observations made with the utmost care in different parts of the globe, have satisfactorily proved the generality of the phenomena.

The following Table of the result of observations made between the parallels of latitude 25° S. and 55° N., has been extracted from a work of Baron de Humboldt, who, with his characteristic zeal for the promotion of science, has expended immense labour in drawing up a connected view of this interesting phenomenon.

TABLE LIV. *Result of the Observations of the Horary Variations made between the Parallels of Latitude 25° South and 55° North, from the level of the Ocean to the elevation of 1400 toises.*

Zones.	Names of the Observers.	Limit-hours. Minima after midnight.	Limit-hours. Maxima of the morning.	Limit-hours. Minima afternoon.	Limit-hours. Maxima of the evening.	Mean extent of the oscillations of the barom. (in hundredths of millim.)	Places of Observation.
		h	h	h	h		
Equator.	Lamanon and Monges	−4	+10	−4	+10	......	Equatorial and Atlantic Ocean.
North and South Torrid Zone.	Humboldt & Bonpland ...	−4½	+ 9¼	−4½	+11	2·55	Equatorial America, from 23° N. lat. to 12° S. lat. between 0° and 1500 toises of elevation.
	Duperrey	−3	+ 9	−3½	+11¼	3·40	Payta (on the coast of Peru), lat 5° 6′ S.
	Boussingault	......	+ 9½	−3½	+10	2·44	La Guayra, lat. 10° 36′ N.
	and Rivero ...	−4	+ 9	−4	+10	2·29	Santa Fé de Bogota (lat. 4°35′ N.) height 1366 t.
	Horsburgh ...	−4	+ 8½	−4	+11	......	Indian and African Sea, lat. 10° N., 25° S.
	Langsdorff & Horner	−3½	+ 9¾	−4	+10½	......	Equatorial Pacific Ocean.
	Sabine	−5	+ 9½	−3¾	+10	......	Sierra Leone, lat. 8° 30′ N.
	Kater	−5	+10½	−4	+10½	......	Table-land of Mysore, (lat. 14° 11′ N., height 400 t.) Rainy season.
	Simonoff	−3½	+ 9½	−3½	+ 9¾	......	Pacific Ocean, from lat. 24° 30′ N., to 25° 0′ S.
	Richelet	−5	+ 9	−5	+10	......	Macao, lat. 22° 12′ N.
	Balfour	−6	+ 9¼	−6	+10	......	Calcutta, lat. 22° 34′ N.
	Dorta, Freycinet, Eschwege ..	−3	+ 9¼	−4	+11	2·34	Equinoctial Brazil, at Rio Janeiro (lat. 22° 54′ S.), and at the Missions of the Coroatos Indians.
	Hamilton	......	......	......	......	......	Table-land of Katmandoo (in India) lat. 27° 48′ N.

TABLE LIV. *Result of the Observations of the Horary Variations made between the Parallels of Latitude 25° South and 55° North, from the level of the Ocean to the elevation of 1400 toises.* (*Continuation.*)

Zones.	Names of the Observers.	Limit-hours. Minima after midnight.	Maxima of the morning.	Minima afternoon.	Maxima of the evening.	Mean extent of the oscillations of the barom. (in hundredths of millim.)	Places of Observation.
Tropic.	Leopold de Buch	......	h +10	h −4	h +11	1·10	Las Palmas, in the Island Grand Canaria, lat. 28° 8′ N.
Temperate Zone.	Coutelle	−5h	+10	−5	+10½	1·75	Cairo, lat. 30° 3′.
	Marque-Victor	summer winter	+ 8½ +10	−5½ −2½	+11	1·20	Toulouse, lat. 43° 34′. (Mean of five years.)
	Billiet	summer winter	+ 7½ +10	−3 −2	......	1·00	Chambery, lat. 45° 34′ (height 137 t.)
	Ramond ...	summer winter	+ 8 + 9	−4 −3	+10 + 9	0·94	Clermont-Ferrand, lat. 45° 46′ (height 210 t.)
	Herren-schneider ...	−5	+ 8½	−3½	+ 9½	0·80	Strasbourg, lat. 48° 34′. (Mean of six years.)
	Arago	......	+ 9	−3	......	0·72	Paris, lat. 48° 50′. (Nine years of the most precise observations.)
	Nell de Breautté ...	......	+ 9	−3	......	0·36	La Chapelle, near Dieppe, lat. 49° 55′.
	Sommer and Bessel.........	......	+ 8½	−2½	+10	0·20	Kœnigsberg, lat. 54° 42′. (Eight years.)

The astonishing regularity in the periods of this oscillation over so large a portion of the surface of the globe, and its gradual decrease as we proceed from the equator to the high latitudes, are thus ascertained in the most unexceptionable manner.

Now, the hypothesis which I had formed to account for these horary oscillations not only indicated this gradual decrease, but required that, passing by a neutral point, they should recur in the latitudes beyond in an opposite direction. Such an idea had not previously been suggested, within my knowledge, by any one; and no experiments existed that I was acquainted with which bore upon the point. Whilst considering the subject, it occurred to me that Captain Parry's, then recent, observations at Melville Island, might possibly afford some light upon this interesting question. Upon consulting, however, the meteorological register, as published in his *Journal*, I was disappointed to find, that it only recorded the maximum and minimum height of the barometer in the twenty-four hours, without mentioning the periods of their recurrence. I happened, very fortunately, to discourse with Colonel Sabine upon the subject, and he assured me, that the observations were made and entered four or six times a day with the utmost regularity, and very obligingly offered to apply to the Admiralty for liberty to inspect the manuscript. His application was immediately complied with, and I was favoured with the loan of the original registers.

I found, upon inspection, that the journal had been kept with the greatest precision, and the height

of the barometer had been entered, during part of the time, at four regular periods, viz., 6 A.M., noon, 6 P.M., and midnight; and the remainder of the time six times in the twenty-four hours, viz., 4 A.M., 8 A.M., noon, 4 P.M., 8 P.M., and midnight. It was therefore with the greatest interest that I undertook to arrange the observations for the purpose of this inquiry. I selected the twelvemonth from Sept. 1819, to August 1820, during which time the *Hecla* was constantly between latitudes 74° and 75°, and the greater part frozen up in Winter Harbour. The following Tables exhibit the results of my calculations. The first contains the monthly mean heights of the barometer and thermometer, taken four times in the day from September to February and part of March, and the second the monthly means taken six times in the day, from the latter part of March to August inclusive.

These Tables present a complete confirmation of the opinion which I had formed from theory.

In the first, including the winter half year, it will be observed, that the mean temperature scarcely varied between noon and midnight, the effect of the remote equatorial expansion was therefore unopposed; and the barometer constantly rose from 6 A.M. to 6 P.M., in coincidence with the fall in the lower latitudes. From 6 P.M. to 6 A.M. it as regularly fell.

In the second half of the year, while the sun was above the horizon, the daily variations of temperature were considerable, and the effect less regular; but, nevertheless, the barometer constantly rose from noon to 8 P.M., and then descended to midnight.

I am enabled, by the publication of the account of the Expedition to the Rocky Mountains of America, under the command of Major Stephen Long, to subjoin from their Meteorological Journal, for the same year, a comparison of the motions of the barometer at three different periods of the day, almost upon the same meridian, and at a distance of 33° of latitude. The expedition took up their winter quarters at "Engineer Cantonment," in latitude 41° 25′ N., and longitude 95° 43′ W., almost the centre of the great North American continent, and the following Table contains my calculations of the means of the observations made during their stay in this situation.

ON BOARD THE HECLA, BETWEEN LATITUDE 74° AND 75°.

TABLE LV. *Shewing the Mean Height of the Barometer and Thermometer at Four different Hours of the Day at Melville Island.*

1819.		6 A.M.		Noon.			6 P.M.		Midnight.		
		Temp.			Temp.			Temp.	Temp.		
Sept. .	. . .	+21·5	−29·884	+29·906	+23·7	. . .	+29·920	+22·7	+21·3	−29·890	
Oct. .	. . .	− 4·	−29·777	+29·808	− 2·8	. . .	+29·840	− 3·9	− 5·	−29·825	
Nov. .	. . .	−21·	−29·935	+29·946	−20·1	. . .	+29·946	−20·1	−21·2	−29·937	
Dec. .	. . .	−23·	−29·874	−29·872	−21·	. . .	+29·881	−21·1	−21·6	−29·893	
Jan. .	. . .	−30·3	−30·040	−30·036	−30·	. . .	+30·068	· 29·9	−30·4	−30·063	
Feb. .	. . .	−32·8	−29·741	+29·758	−30·8	. . .	+29·782	−32·6	−33·5	−29·771	
March (10 Ds.)	. . .	−19·1	−29·551	+29·561	−14·5	. . .	+29·614	−18·5	−20·5	−29·571	
			208·802	208·887			209·051			208·950	
			29·8288	29·8410			29·8644			29·8500	Max. 6 P.M. 29·8644
			− ·0212	+ ·0122			+ ·0234			−·0144	Min. 6 A.M. 29·8288
											Difference ·0356

On Board the Hecla, between Latitude 74° and 75°.

Table LVI. *Shewing the Mean Height of the Barometer and Thermometer at Six different Hours of the Day at Melville Island.*

1819.	4 A.M.	8 A.M. Temp	8 A.M.	Noon.	Noon. Temp.	4 P.M.	8 P.M.	8 P.M. Temp.	Midnight. Temp.	Midnight.	
March (20 Ds.)	−29·894		−29·885	−29·880		+29·902	+29·906			+29·910	
April .	−29·963	- 9·2	+29·976	−29·971	- 3·7	+29·973	+29·988	- 8·1	−12·8	−29·987	
May .	+30·116	+15·	+30·119	−30·099	+20·3	30·099	+30·109	+18·2	+13·1	30·109	
June .	+29·826	+36·3	+29·828	−29·821	+38·6	+29·823	+29·819	+36·5	+33·6	−29·817	
July .	+29·668	+42·5	+29·675	−29·674	+45·	+29·663	+29·665	+42·7	+39·1	−29·660	
August	−29·733	+32·7	−29·727	−29·734	+35·5	+29·737	+29·738	+32·	+30·5	−29·735	
	179·200		179·210	179·179		179·197	179·225			179·218	
	29·8666		29·8683	29·8631		29·8661	29·8708			29·8696	Max. 8 P.M. 29·8708
	− ·0030		+ ·0017	− ·0052		+ ·0030	+ ·0047			− ·0012	Min. noon 29·8631
											Difference ·0077

TABLE LVII. *Showing the Mean Height of the Barometer and Thermometer at Three different Hours of the Day at the Rocky Mountains of North America. Lat.* 41° 25′; *Long.* 95° 43′.

	Morning.		Noon.		Evening.	
	Temp.	Barometer.	Temp.	Barometer.	Temp.	Barometer.
1819.						
September	60·	+28·650	80·3	−28·634	72·1	−28·633
October	40·3	+28·812	61·8	−28·730	55·6	−28·720
November	35·8	+28·705	48.	−28·607	46·	−28·604
December	20·2	+28·808	29·	−28·660	26·3	+28·703
1820.						
January	12·1	+28·966	16·9	28·966	10·8	−28·954
February	22·1	+28·618	36·5	−28·501	32·	+28·550
March	27·4	+28·902	41·8	−28·815	37·	+28·881
April	45·7	+28·465	65·4	−28·267	62·4	−28·261
May	55·2	+28·496	69·7	−28·309	65·8	+28·370
	Mean	28·713		28·609		28·630

Maximum, Morn. 28·713
Minimum, P.M. 28·609
Difference ·104

Notwithstanding the height of this latter station above the sea, we still find the same principle to prevail, and it is satisfactory to discover amongst so many various circumstances, whose influence upon the results are at present unknown, that, in accordance with the theory, on the same hours of the same months, the barometer, upon nearly the same meridian, periodically rose in latitude 74° 47′, and fell in latitude 41° 25′.

Upon the return of Captain Parry's second expedition from the northern coast of America, I was extremely anxious again to bring my hypothesis to the

test of experience, and for this purpose was favoured upon application, with the loan of Captain Lyon's Meteorological Journal. This, as well as all other nautical registers which I have had an opportunity of examining, has been kept with the utmost precision and neatness; and it is highly gratifying to find so much attention to the interests of science amongst our naval officers, who have such opportunities of enlarging our acquaintance with the different climates of the globe. The periods of the day were almost as favourable as possible to the comparison, but the latitudes were not as far removed as that of Melville Island from the influence of variations of daily temperature. The following Table presents the monthly means of the observations for two years, during which the Hecla was confined between the latitudes 66° and 70°.

Table LVIII. *Showing the Mean Heights of the Barometer and Thermometer at Four different Hours of the Day on board H.M.S. Hecla, between the Latitudes 66° and 70°.*

Date.	A.M. 4.		A.M. 8.	P.M. 4.		P.M. 8.
1821.	BAR.	THER.	BAR.	BAR.	THER.	BAR.
August - -	29·835	33·5	29·846	29·848	39 9	29·825
September -	29·958	29·8	29·974	29·973	34·3	29·977
October -	29·881	8·9	29·876	29·889	17·6	29·898
November -	30·166	2·7	30·156	30·165	12·6	30·159
December -	29·904	−19·2	29·898	29·914	−11·5	29·918
1822.						
January -	29·921	−26·9	29·924	29·933	−20	29·952
February -	29·762	−27·5	29·746	29·753	−18·5	29·761
March - -	29·849	−17	29·854	29·864	− 3·8	29·852
April - -	29·895	− 0·2	29·893	29·907	+13·9	29·918
May - -	29·985	+13·5	29·957	29·973	+31·5	29·978
June - -	29·886	26·9	29·877	29·897	38·2	29·868
July - -	29·682	32·7	29·693	29·694	40·3	29·702
August - -	29·643	31·5	29·636	29·661	36·5	29·667
September -	29·883	22·2	29·883	29·895	28·3	29·894
October -	29·967	10·7	29·981	29·981	18·1	29·985
November -	29·875	−22·6	29·876	29·884	−13·4	29·882
December -	29·756	−32·5	29·739	29·741	−25·4	29·726
1823.						
January -	29·877	−20·2	29·902	29·898	−10·6	29·893
February -	29·904	−24·9	29·906	29·905	−13·4	29·907
March - -	30·050	−24·1	30·055	30·050	−12	30·061
April - -	29·957	− 9·	29·955	29·957	+ 7·5	29·954
May - -	29·929	+16·9	29·916	29·920	33·3	29·921
June - -	29·922	23·4	29·910	29·909	41·2	29·909
July - -	29·507	33·2	29·499	29·509	43·8	29·508
Mean - -	29·874	....	29·872	29·880	....	29·879
Difference	−·005	....	−·002	+·008	....	−·001

It appears from this table that the rise in the mercurial column from 8 A.M. to 4 P.M. was nearly constant; and upon further examination it will be found that in the only two exceptions of any amount, namely, the months of January and March, 1823, some unusual influence prevailed in the atmosphere. The first was distinguished by an unusually high mean temperature, and frequent storms of wind. Captain Parry remarks in his *Journal*, "From the morning of the 24th till midnight on the 26th, the mercury in the barometer was never below 30·32 inches, and at noon on the latter day had reached 30·52 inches, which was the highest we had yet observed it in the course of this voyage. This unusual indication of the barometer was followed by hard gales on the 27th and 28th, first from the south-west, and afterwards from the north-west, the mercury falling from 30·51 inches at 8 P.M. on the 26th, to 30·25, about 5 P.M. on the 27th, or about 0·26 of an inch in nine hours before the breeze came on. At midnight on the 27th, it had reached 29·30; and on the following night 29·05, which was its minimum indication during the gale. These high winds were accompanied by a rise in the thermometer very unusual at this season of the year, the temperature continuing above 0° for several hours, and very near this point of the scale for the whole two days."

The month of March, on the contrary, was as much below the mean temperature, as January was above it; and the observation renders it probable that the usual course of the season was modified by some extraneous cause.

I am aware that it may be objected, that these observations were not made with all the precision that the accurate determination of such small quantities requires, and particularly that the heights of the barometer were not corrected for the variations of temperature. The objection, to some extent, is certainly valid, and it is much to be lamented that the advantages of the utmost attainable degree of precision in these observations had not been duly appreciated; but when it is recollected that the instrument made use of was placed in the cabin of the ship, where considerable pains were taken to maintain an equal temperature, it will be found that less importance attaches to the omission in this particular instance than might at first be supposed. In this voyage, more especially, the precautions which were adopted to secure this important end were eminently successful. It appears, for instance, by Captain Parry's register, that in the months of October and November, the mean temperature of the external air varied 32°, while that of the air of the lower deck only varied 5°; so that the changes in the course of the twenty-four hours could have been scarcely appreciable.

The return, however, of Captain Parry's last expedition left nothing to be desired in the way of accuracy. The instruments which were provided upon this occasion were of the first excellence; and the barometers were independently graduated and compared with one another, as well as with the standard of the Royal Society. The proper corrections were applied as the observations were made; and the me-

teorological journal kept by Lieut. Foster, is a complete model of all that is desirable in such a register. As opportunities will not probably soon again occur for making similar observations in such high latitudes, it is well that it should be known that this series, and this alone, is to be depended upon for accurate purposes; and they will, doubtless, hereafter furnish important data in resolving the question of the mean height of the barometer at the level of the sea, in different latitudes, which the carelessness of observers and instrument-makers does not yet permit to be determined in more accessible regions.

While upon this subject, it may be as well to mention, that the thermometric observations are entitled to equal confidence. The thermometers, at the lowest temperatures, agreed within three degrees with one another, while, upon former occasions, there was a difference of many degrees.

At my particular request, the register of the barometer was kept in such a way as to elicit most advantageously the phenomena of the horary oscillations. The following observations and tables of results are extracted from Captain Parry's interesting *Journal*:—

"The most rigid attention to the observation and correction of the column during several months, discovered an oscillation amounting only to ten thousandth parts of an inch; the times of the maximum and minimum altitude appear, however, decidedly to lean to 4 and 10 o'clock, and to follow a law directly the reverse, as to time, of that found to obtain in temperate climates, the column being *highest at* 4

and *lowest at* 10 *o'clock*, both A.M. and P.M. The whole of the observations, being comprised in the 'Meteorological Abstracts,' with the general results stated at the bottom of each, can be consulted with great convenience; and the following Table will afford one comprehensive view of six months' observations on this interesting subject."

ABSTRACT.

"The mean result of six months' observations at Port Bowen, (N. lat. 73° 48′, long. 88° 54′,) in which the barometer was registered at the hours of 3, 4, 9, and 10, are here collected into one Table; and in a second Table is given a comparative view of three months' observations, in which it was registered at the additional hours of 5 and 11. On reference to these Tables, it will be seen that the general tendency seems to indicate high barometer at 4 o'clock, and low at 10 in the morning. The evening tide, though less regular, is also highest at 4, but lowest at 11 o'clock. The changes, however, are in themselves so extremely minute (amounting to only the hundredth part of an inch), that a sudden alteration in the atmosphere causing the barometer to rise or fall rapidly on any one day, is sufficient to introduce an anomaly sensibly affecting the mean result of a whole month."

TABLE LIX. *Comparative View of the Mean Pressure of the Atmosphere at the Hours of* **3, 4, 9,** *and* **10** A.M. *and* P.M., *during six successive* **Months, 1824, 25.**

DURING THE MONTH OF	MEAN PRESSURE of the ATMOSPHERE at							
	3 A. M.	4 A. M.	9 A. M.	10 A. M.	3 P. M.	4 P. M.	9 P. M.	10 P. M.
1824.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
November - -	29·8943	29·8990	29·8986	29·8971	29·9067	29·9037	29·8971	29·8909
December - -	29·8726	29·8767	29·8729	29·8687	29·8693	29·8695	29·8663	29·8551
1825.								
January - - -	29·7610	29·7668	29·7580	29·7541	29·7614	29·7599	29·7677	29·7617
February - -	29·8921	29·8938	29·8889	29·8788	29·8864	29·8890	29·8865	29·8835
March - - -	30·1064	30·1103	30·1101	30·1041	30·1095	30·1105	30·1080	30·1049
April - - - -	30·0639	30·0697	30·0653	30·0594	30·0698	30·0681	30·0739	30·0665
Means - - -	29·9317	29·9359	29 9323	29 9270	29·9338	29·9334	29·9332	29·9271

TABLE LX. *Comparative View of the Mean Pressure of the Atmosphere at the Hours of* 3, 4, 5, 9, 10, *and* 11 *A.M. and P.M., during three successive Months*, 1825.

DURING THE MONTH OF	MEAN PRESSURE of the ATMOSPHERE as observed at											
	3 A.M.	4 A.M.	5 A.M.	9 A. M.	10 A.M.	11 A.M.	3 P.M.	4 P.M.	5 P.M.	9 P.M.	10 P.M.	11 P.M.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
Feb.	29·8921	29·8938	29·8890	29·8889	29·8788	29·8811	29·8864	29·8890	29·8899	29·8865	29·8835	29·8812
Mar.	30·1064	30·1103	30·1088	30·1101	30·1041	30·1028	30·1095	30·1105	30·1079	30·1080	30·1049	30·1025
April	30·0639	30·0697	30·0670	30·0653	30·0594	30·0610	30·0698	30·0681	30·0712	30·0739	30·0665	30·0649
Means	30·0208	30·0246	30·0216	30·0214	30·0141	30·0150	30·0219	30·0225	30·0230	30·0228	30·0183	30·0162

Thus, I think, that I am entitled to say, that the test which I had proposed, to ascertain whether my hypothesis of the cause of the horary oscillations of the barometer were founded upon the laws of nature, has confirmed its truth, and furnished results which I was enabled to anticipate by its conclusions, and its conclusions alone. Further consideration has suggested to me other unforeseen conditions of the problem, which the proposed solution appears to me quite sufficient to satisfy.

Baron Humboldt observes, that, "in the torrid zone the limit hours (that is, the instants when the oscillations attain the *maximum* and *minimum*) are the same at the level of the sea, and on table-lands at the elevation of from 1300 to 1400 toises. It is asserted, that this isochronism is not manifested in some parts of the temperate zone, and that at the convent of the Great St. Bernard, for instance, the barometer lowers at the same hours when it rises at Geneva*."

This assertion is confirmed by the registers of the Palatine Society, in which it will be found that the barometer upon the summit of St. Gothard rose from morning to afternoon, and fell from afternoon to night, with almost as much regularity as it followed the contrary course at the level of the sea. It is true that 2 o'clock, the time of the afternoon observation, is not the hour the best calculated to exhibit the full amount of the oscillation, but it sufficiently establishes its general tendency.

* *Personal Narrative*, vol. vi., p. 758.

Now, in what way does the hypothesis meet this exception to the general law? At p. 113 of the preceding Essay I have shown, that the weight of a column of air at its base will not be affected by any alteration of temperature, but that the weight of any of its superior sections will be affected by the contraction and expansion. As the column expands, the barometer, which measures the pressure of any upper section, will rise in proportion to its height above the base, on account of the different distribution of the ponderable matter which takes place.

The summit of an insulated mountain, or the narrow ridge of a chain of mountains, may be considered to approximate in their situations, with regard to the atmosphere, to a section of an atmospheric column of an equal height; for, although it is true that the column of the atmosphere immediately above such summit or ridge, rests upon it as a base, yet this base, presenting as it were but a point, or a line, with regard to the ambient mass, the incumbent air must necessarily be subject to all the fluctuations of the elastic ocean, by which it is hemmed in. The great body of the atmosphere expanding with the rising heat of the day flows over the insulated station, and obliterates the effect of that regular drain which would be due to it, at a lower level, from the cause which we have been investigating.

The same reasoning does not apply to extensive table-lands, however lofty: the extent of the basis upon which the aërial fluid rests, in such situations, constitutes it an independent atmosphere; in which

we find the same effects following the same causes, as in equally extended plains at the level of the sea.

Trusting to the sufficiency of this explanation, and the general correctness of the hypothesis, I will venture to anticipate, that although in the torrid zone, the horary oscillations of the barometer are found upon *table-lands* at the height of 1300 or 1400 toises, to be isochronous with those at the level of the sea, if ever a sufficient number of observations should be obtained at equal heights upon *insulated peaks*, in the same latitudes, they will indicate that the regular law is masked by the action which I have endeavoured to explain; while, on the other hand, with Baron Humboldt, I do not doubt that, notwithstanding the contrary result upon the summits of St. Gothard and St. Bernard, "in the elevated plains of La Mancha in Spain, at 320 toises we should see the barometer ascend at the same hours as at Valencia or Cadiz."

It has been attempted to account for the horary oscillations of the barometer by opposite waves of the atmosphere produced by and moving under the calorific influence of the sun in its daily course from east to west: and it has been observed that the portion of the globe situated between the meridians of the rising and setting sun becomes warmed by this influence. Placing ourselves upon any meridian at noon, the maximum of this heating power will be manifested between the meridians of 9 A.M. and 3 P.M. In this interval the air expands, ascends and passes into the neighbouring regions, and the barometer falls; but it rises under the weight of the masses of air which have

overflowed between the meridians of 9 and 3 o'clock, and then from 3^h to 21^h (9 A.M.)—[On account of some obscurity which I cannot clear up satisfactorily to myself, I will give the remainder of the quotation in the original, the French translation by M. Martins being no less obscure.]

"In der zweiten Gegend erkaltet die Luft, nachdem die Zeit der grössten täglichen Wärme vorüber ist. So verbreitet sich diese Bewegung nach und nach aus einer Gegend in die benachbarte und wird dadurch dem Theile mitgetheilt, welcher, von unserm Meridiane ausgerechnet, zwischen den Nachtkreisen liegt. Das Barometer sinkt daher von 9^h bis 16^h, weil die Atmosphäre durch Verminderung der Kälte während der Nacht an Dichtigkeit, durch den Antheil, welcher ihre obern Schichten den beiden benachbarten Regionen gegeben haben, aber an Höhe verloren hat.

"Wenn sich nach dieser Hypothese auch die beiden Maxima und das Minimum am Tage erklären lässt, so scheint es auf den ersten Anblick schwierig, daraus das Minimum am Morgen abzuleiten. Aber zur Zeit wo dieses erfolgt tritt östlich von dem Orte das Minimum der Temperatur ein, die Atmosphäre hat dann die geringste Höhe, und nothwendig fliesst dahin ein Theil der Luftmasse aus den westlicher gelegenen Gegenden, wodurch hier das Barometer sinkt*."

Of this hypothesis it may be sufficient to remark, that it does not attempt to explain the decrease of the

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* LUDWIG FRIEDRICH KÄMTZ, *Lehrbuch der Meteorologie.* Halle, 1832, ii. 281.

amount of the horary oscillations from the equator towards the poles, and indeed is irreconcileable with that well-marked phenomenon. The differences of temperature between day and night are at least as great in the higher latitudes as in the lower, and if the oscillations were the consequence of a lateral flow of the air dependent upon them, they would not be greater between the tropics than in the temperate zones. Still less will it account for the neutral line, and the reappearance of the oscillations with contrary signs as we approach the poles. There is no doubt, as we have already shown, that a lateral deflection of the great meridional currents is produced by the expansive power of the maximum temperature as it passes from east to west along the successive meridians, but this alone will not explain the phenomena.

M. Dove has assigned another cause to these variations; "the pressure of the atmosphere on the barometer being the sum of the pressures of the dry air and the vapour of water, the barometric column is composed, so to speak, of two parts; one corresponding to the air, the other to the vapour. Now, when the temperature rises, the density of the air diminishes, but the tension of the vapour increases; and it is not easy to determine the relations which exist between the diurnal variations of the barometer and thermometer, by taking account of each of these two influences. To obtain this M. Dove analyzed the observations made by Neuber at Apenrade with one of Daniell's hygrometers, and having calculated the tension of vapour for each hour of the day, subtracted it from the barometric columns."

He imagined that he thus obtained the pressure of the dry air alone, and of which there was but one *maximum* and *minimum*, the former occurring about 1 A.M., and the latter about 2 P.M. These he ascribes to the diurnal variations of temperature, with the *maximum* and *minimum* of which they are nearly coincident. "This single *maximum* and *minimum* are also augmented by the vapour of water that rises during the day. In the morning, when the pressure of the dry air diminishes, not only does the tension of the vapour compensate this effect, but it makes the column rise; and it attains its maximum when the pressure of the air begins to diminish. For the same reason we find a *minimum* in the morning, because the diminution of the vapour during the night is more rapid than the increase of the pressure of the dry air*."

Now, we have already shown, that the total pressure of the atmosphere of vapour upon the barometric column cannot be estimated by the tension of the lower stratum, and that the deduction of its amount from the height of the mercurial column will not afford us the amount of the dry air. The law of the progression of the elasticity of vapour mixed with an atmosphere of gas, must be totally different from that of the gas itself; and we have shown there is reason to suppose that it is interstratified in beds of different degrees of force, each of which, in the act of diffusion, adds its different quota to the general pressure.

Moreover, the results which have been derived by

* KAEMTZ, Martins' Translation, p. 271.

M. Dove from one year's observations at Apenrade, are not confirmed by those of observations made at other stations, and indeed are directly opposed to them. Observations between the tropics, where the variations of the dew-point are the smallest, and the amplitude of the horary oscillations the greatest, are wholly inconsistent with this view.

It is with considerable reluctance that I here find myself called upon to make some remarks upon the observations of a distinguished writer upon this subject, namely, Professor James D. Forbes, of Edinburgh, who, in a Paper on the Horary Oscillations of the Barometer, published in the *Transactions of the Royal Society of Edinburgh for* 1834, (seven years after the publication of the second edition of my *Essays*,) has made some allusions to my hypothesis.

In the first place, referring to my examination of Captain Parry's registers of the barometer at Melville Island, he says,—"It is rather surprising that Mr. Daniell should have so overlooked this source of error," (viz., the want of the correction for the temperature of the mercurial column,) "as to have placed the utmost confidence (in the first edition of his work,) in the existence of oscillations which might have been caused by a change of temperature, amounting to little more than 1° Fahrenheit."

I have already shown, that it was as a deduction from my hypothesis, that I was led to seek for any, even the slightest, indication of an accumulation of the atmosphere in polar regions, corresponding to the deficiency in the equatorial latitudes, and *vice versâ;* and in my examination of the registers upon the return of Captain

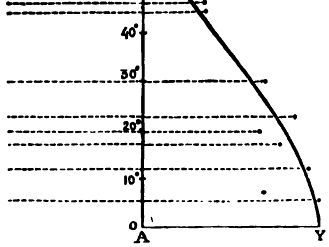
Parry's second expedition, I have expressly stated, that "I am aware that it may be objected that these observations were not made with all the precision that the accurate determination of such small quantities requires, and particularly that the heights of the barometer were not corrected for the variations of temperature." I then proceeded to give my reasons, (as above, p. 289), for considering them, though not worthy of the *utmost confidence*, more trustworthy than they would have been under ordinary circumstances.

Professor Forbes proceeds to observe, that "the last voyage of Captain Sir Edward Parry afforded results worthy of the highest confidence, from observations with excellent instruments of which the indications were registered with an assiduity and precision which puts to the blush any thing of the kind, at least in Britain, destined to the furtherance of the science of meteorology. These excellent observations indicate the existence of all the oscillations observed in lower latitudes, including that at 4 A.M., which has rarely been observed in any part of the globe, and give all the values with a negative sign relatively to the ordinary oscillations."

Professor Forbes has, however, omitted to state that "the register of the barometer was kept in such a way as to elicit most advantageously the phenomena of the horary oscillations, *at my particular request*," and with the direct intention of thereby confirming or refuting my hypothesis. It is of less importance to remark that the instruments were all constructed and compared under my immediate superintendence; and most assuredly all would have been fruitless without

the admirable precision and unwearied assiduity with which the officers of the expedition carried out their instructions.

Professor Forbes accuses me of treating the question "as one of quality and not of degree," or of considering the change of sign in the amount of the oscillations "as an anomaly in the quality of the effect, or as a change *per saltum* in the course of nature," whereas nothing, I should have imagined, could be more clear than that I had considered it as an effect as continuous as the law of the daily change of temperature, upon the action of which upon the two great currents of the atmosphere I had conceived it to depend. Whether further observation will confirm or refute my hypothesis in part or in whole may perhaps be considered doubtful, but it will always be certain that it has been the means of eliciting a fact which must henceforth be of primary importance in



any explanation of the phenomena, and which never had been even "suspected" till it was put forth.

Professor Forbes has given it as his opinion that "the phenomenon is deducible from the abstract consideration of quantity." This I must freely confess myself incapable of understanding; but he has constructed a curve from an empirical formula which appears to represent very closely the observed amount of oscillation at the level of the sea as depending upon latitude. This I subjoin: the observed oscillations will be found projected by means of round dots, the distances of which from the line A X, representing the quadrant of latitude, indicate the amount.

The agreement of the calculated with the observed oscillations is shown in the following Table:

TABLE LXI. *Comparison of the observed and calculated Amounts of the Horary Oscillations of the Barometer in different Latitudes.*

Place.	Latitude.	Oscillation.		Difference.
		Observed.	Calculated.	
	° ′	Millimetres.	Millimetres.	Millimetres.
Payta . .	5·6 S	2·66	2·620	− ·04
Cumana .	10·28	2·55	2·525	− ·02
Otaheite . .	17·29 S	2·15	2·312	+ ·16
Isle of France	20·10 S	1·82	2·206	+ ·39
Rio Janeiro .	22·54 S	2·45	2·087	− ·36
Cairo . .	30·3	1·89	1·732	− ·16
Toulouse . .	43·36	1·00	0·971	− ·03
Clermont .	45·46	0·94	0·851	− ·09
Paris . .	48·50	0·76	0·685	− ·07
Maestricht .	50·51	0·57	0·579	+ ·01
Königsberg .	54·42	0·20	0·388	+ ·19
Edinburgh .	55·55	0·27	0·332	+ ·06
Port Bowen .	73·48	− 0·22	− 0·256	− ·04

The further development of the subject must now probably await further and more accurate and combined observations; "observations of perfect regularity, combined with precision as to the hours of observation, such as can alone be looked for from the registers of public and learned bodies;" and I may add from the results of my observations with a water-barometer, which I shall hereafter detail, that the greater delicacy and freedom of action of that instrument must be substituted for the comparatively sluggish motions of the mercurial column before all the nicer points of the problem can be determined.

§ 2. ON THE IRREGULAR OSCILLATIONS OF THE BAROMETER.

Amongst the phenomena for which I have endeavoured to account in the previous Essay, I have slightly alluded to the coincidence which was known often to occur in the movements of barometers situated at great distances from each other; and mentioning the observation that this unison of action extends further in the direction of the latitude than in that of the longitude, I remarked that the fact confirmed the theory: for, as the grand currents of the atmosphere flow nearly in the direction of the meridians, any irregularity in their courses would most readily be propagated in the same line. Further consideration convinced me that this argument should have been greatly extended; and I perceived that a strict adherence to the legitimate conclusions of the hypothesis

would establish, not only a partial and frequent coincidence of the aërial undulations in different latitudes, but a wide-extending and constant agreement. The want of combination in the meteorological observers of the present day made me despair of being able to bring the idea to the test of sufficient experiments, till accident threw in my way a register of inestimable value.

My friend Mr. Howard some time ago obliged me with a loan of some of the volumes of the *Ephemerides* of the Meteorological Society of the Palatinate: a work which, if it had been continued with its original spirit to the present time, would probably have left little to be desired in the way of observation; and which, even in its present state, would be found by the diligent inquirer to contain more *data* for a correct history of European weather than all other works upon the same subject taken together. During a tour which I made in Germany, I succeeded in obtaining a complete copy of these Transactions, from their commencement in 1781, to their termination in 1792. As this record is very little known in this country, and in its complete state very scarce, I shall be excused for giving a short account of its origin, and that of a society which might, undoubtedly, afford the most perfect model of a similar institution at the present day for promoting the Science of Meteorology.

The Meteorological Society of the Palatinate was established in the year 1780, under the auspices of the Elector Charles Theodore, who not only gave it the support of his public patronage, but entered with

spirit and ability into its pursuits, and furnished it with the means of defraying the expense of instruments of the best construction, which were gratuitously distributed to all parts of Europe, and even to America. One of the first acts of the Association was, to write to all the principal universities, scientific academies, and colleges, soliciting their co-operation, and offering to present them with all the necessary instruments properly verified by standards, and free of expense.

The offer was immediately accepted by thirty societies; and the list of distinguished men who undertook to make the observations shows the importance which was attached to the plan, and the zeal with which it was promoted in every part of the Continent. Amongst those who, for the good of science, undertook and executed this daily drudgery, we find the names of Hemmer, Weis, Planer, Senebier, Bugge, Van Swinden, König, Cotte, Egel, Pictet, Toaldo, and Euler. The Secretary Hemmer appears to have been indefatigable in his exertions to perfect this truly princely plan of operations; and, even now, but little could be added to the precautions taken in the preparation of instruments which he describes, or to the ample instructions for their use, which he transmitted with them. Some idea may be formed of the comprehensive scale of the register, when it is known that it contains observations, three times in the day, of the barometer, thermometer in the shade and in the sun, hygrometer, magnetic-needle, direction and force of the wind, quantity of rain and of eva-

poration, the height of any neighbouring water, the changes of the moon, the appearance of the sky, and the occurrence of meteors and of the Aurora Borealis. To these must be added, in some places, observations upon the electrical state of the atmosphere, upon the progress of vegetation, the prevalence of disease, changes of population, and migration of animals. The field of observation extended from the Ural Mountains in the east, to Cambridge in the United States in the west; and from Greenland and Norway in the north, to Rome in the south. This range included also stations upon three high mountains in Bavaria, and upon the summit of St. Gothard. The observations of each year are summed up, and compared with those which precede, in copious and most laborious tables of mean and extreme results; and many very interesting essays upon various branches of Meteorology are interspersed throughout the volumes. Unfortunately for science, the Secretary Hemmer died in the month of May, 1790, and from that time the Society appears to have languished, and finally to have become extinct amidst the troubles and the wars of the French Revolution.

Amongst other valuable suggestions, in these volumes, upon the proper uses of meteorological observations, I have found the first exemplification of the method of representing the oscillations of the barometer by a curved line upon a scale—a method of the utmost consequence in connecting detached observations, and exhibiting their mutual relations. The instances of this application in the volumes before

me are very few, and for very short intervals; but it has been employed, upon a small scale, to show the accordance of great changes of the mercurial column at distant points. It is by an extension of this plan that I shall now proceed to show, that, within certain limits, the movements of the barometer coincide by some general law over large portions of the surface of the globe. I shall endeavour to trace, as far as the observations will allow, the limits of this coincidence, the particular direction in which it occurs, and the circumstances, if any, which modify its regularity.

Plates III. and IV. represent the oscillations of the barometer at eighteen stations on the continent of Europe for one twelvemonth; they comprehend a space of nearly 18° of latitude, and 14° of longitude. The observations are laid down twice in the day, viz., at 7 A.M., and 9 P.M., upon a scale of English inches, which, however, has been reduced in the engraving; each perpendicular division representing a tenth of an inch, and each horizontal division comprehending a day. The curves have been arranged in order from north to south, commencing with Spidberg, in Norway, and ending with Rome and Padua. In selecting the stations I have endeavoured to confine one set, as much as possible, to the same meridian; while I have chosen a second nearly approaching one another in latitude, but differing widely in longitude.

SPIDBERG, the first station, is a small parish in Norway, situated between Christiana and Frederickshall, within a short distance of the North Sea on its

western side, and of the Baltic on its eastern. The longitude of the place of observation, which was the church and residence of the minister, is represented in the Transactions as 9° 4′ E.; but there must be some mistake in this, as from the locality it cannot be less than 10° 50′ E. The latitude is 59° 30′ N., and the altitude above the level of the sea about 426 feet.

STOCKHOLM, the second station, is situated in about the same degree of latitude, but nearly 8° apart in the longitude. The place of observation was the Observatory close to the shore of the Baltic, above the surface of which it stands about 136 feet.

COPENHAGEN, the third station, is built upon the southern coast of the Cattegat, or entrance of the Baltic. The Royal Observatory, at which the Register was kept, stands about 136 feet above the mean level of the sea; its latitude is 55° 41′ N., and its longitude 12° 40′ E. It is distant about 300 miles to the south-west of the preceding station.

GOTTINGEN, the next in succession, is situated almost exactly on the meridian from which we set out; its longitude being 9° 53′ E., and its latitude 51° 52′. It is about 290 miles distant from the North Sea, above the level of which it stands about 450 feet. The river Leine flows near it, and it is surrounded by moderate hills. The Hartz Mountains rise in the N.E., at a distance of not more than 15 miles.

SAGAN, the fifth station, has been selected as corresponding with the preceding in latitude, viz., 51° 42′ N., but being far removed in longitude, viz.,

15° 27′ E. It is situated upon the Bober, and surrounded on all sides by extensive plains. The place of observation was raised about 60 feet above the level of the river.

Erfurt, the sixth station, again approaches the first meridian, but advances us to the south. Its longitude is 11° 23′ E, and its latitude 51° N. The surrounding country is open.

Brussels, the seventh station, is the most western point of our present comparison, and particularly remarkable, as we shall hereafter have occasion to observe, on account of its being the nearest to the Western Sea. It is situated in a very open country, on the banks of the small river Senne. The latitude is 50° 51′ N., the longitude 4° 28′ E. The barometer was placed about 175 feet above the level of the river.

Prague, the eighth station, carries us again more than 10° to the east; its longitude being 14° 50′ E., and its latitude 50° 5′ N. It is situated in a hilly country upon the banks of the Moldaw.

Mannheim, the ninth station, was the head quarters of the Meteorological Society; and here the observations, under the immediate superintendence of the Secretary Hemmer, were more varied and more complete than in any other place: on this account, as well as on that of its central situation, it furnishes the best standard of comparison for all the other observatories. All the particulars of its situation are most accurately described in the Transactions. It is placed in a vast plain, and nearly surrounded by the waters of the

Necker and the Rhine. Its latitude is 49° 26′ N. and its longitude 8° 31′ E.; not very far removed from the meridian from which we set out. The barometer was placed about 51 feet above the mean level of the Rhine.

RATISBON, the tenth station, is placed upon the Danube, in latitude 48° 56′ N., and longitude 12° 5′.

MUNICH, the eleventh station, is situated about 62 miles to the south of the preceding. It is seated in a plain on the river Iser, in latitude 48° 10′ N., and longitude 11° 36′ E. The barometer was placed about 48 feet above the ground.

PEISSENBERG, or Hohenpeissenberg, the twelfth station, is a mountain of Upper Bavaria, distant not more than three or four miles from the mountains of the Tyrol. The place of observation was its very summit, about 1300 feet above the level of the river Amber, and 1100 above the Leike. Its latitude is 47° 47′ N., and its longitude 10° 59′ E. It is remarked in the Transactions, as a place peculiarly adapted by nature for meteorological observations. Its horizon extends on all sides, but the south, to a distance of above 12 miles; but in the south the Tyrolese Mountains overtop it considerably. It is surrounded by marshy land; and there are no less than three considerable lakes within two miles of it, and several rivers. The northern side of the mountain is covered with wood, and there are large forests in its vicinity. The barometer was placed about 30 feet above the ground.

BUDA, the thirteenth station, is the most eastern point of the present comparison, its longitude being

18° 22′ E., and its latitude 47° 29′ N. It is situated upon the side of a hill upon the banks of the Danube, and surrounded on all sides by hills. The barometer was placed in the Royal Observatory, about 290 feet above the mean height of the river.

GENEVA, the fourteenth station, is situated upon the extensive lake to which it gives its name, in latitude 46° 12′, and longitude 6° 5′. The Rhone takes its course through the city, and is surrounded on all sides by lofty mountains. The level of the lake is about 1350 feet above that of the sea.

ST. GOTHARD, the fifteenth station, was the Hospice of the Capuchin Monks, almost upon the summit of the mountain. It is situated 6800 feet above the level of the Mediterranean Sea. It is surrounded on all sides by lofty rocks, some of which rise to the height of 2000 feet above it. The situation is most open to the north and the south, but it is closely hemmed in on every other quarter. There is a small lake close by the dwelling; it is considerably raised above the forests in its neighbourhood.

MARSEILLES is the sixteenth station, and stands upon the shores of the Mediterranean Sea. Its latitude is 43° 18′ N., and its longitude 5° 27′. The ground upon which it stands is uneven, and it is surrounded on the land side by mountains, some of which are not less than 2500 feet high. The Observatory is built upon one of the highest points of the town, and the barometer was placed at the height of 153 feet above the sea.

ROME, the seventeenth station, is the most south-

ern point to which the observations extend. It is not very far removed from the Norwegian meridian from which we set out, and agrees almost exactly with that of Copenhagen, thus extending the comparison to upwards of 1200 miles in a straight line from north to south. The exact latitude is 41° 54′ N., and the longitude 12° 55′ E. The city is situated upon the river Tiber, which runs through a part of it, and at no great distance from the Mediterranean on the south, and the Adriatic on the north. The barometer was fixed at a height of about 90 feet above the level of the sea.

PADUA, the last station of this comparison, is a few degrees more to the north, being in latitude 45° 23′ N., and longitude 12° 1′ E. It is seated near the upper part of the Adriatic, in a fine plain, at the confluence of the rivers Brenta and Bachiglione. The surrounding country is distinguished by its beauty and fertility. The barometer stood about 60 feet above the level of the sea.

I regret very much my inability to include London amongst the stations of this interesting survey. The Royal Society, as might be supposed, was one of the first scientific bodies to which the Meteorological Society of the Palatinate addressed themselves for co-operation in the great and truly scientific work which they had undertaken; and it is very remarkable, and, to an Englishman, very mortifying to remark, that the answer of the Royal Society to the invitation is the only one amongst a vast number which does not appear in the Transactions. By some unfortunate

coincidence, the years which are included in the *Ephemerides* are precisely those during which no Meteorological Register was published in the *Philosophical Transactions:* so that the comparison fails at a point which, for many reasons, is one of the utmost interest and importance; but particularly on account of the situation of London being on the extreme west of Europe, and of its being surrounded by the waters of the Atlantic Ocean.

The names of the stations are inserted on one side of the plates, and their longitudes and latitudes on the other. In conjunction with the former, I have placed the mean heights of the barometer for the year, by which a judgment may at once be formed of their relative elevations above the level of the sea.

I may here remark that I have laid down several more curves, at intermediate places, which are not included in the plates, for fear of rendering them confused. In selecting the present series, I have been guided in my choice by such circumstances as might be supposed to produce the greatest difference between them. Those which I have omitted all concur in the general result.

The principal fact disclosed by the comparison of observations at all these various points must at once strike the eye of the most careless observer, namely, the near coincidence of all the curves. From the shores of the Baltic to those of the Mediterranean; from the level of the sea to the height of nearly 7000 feet above it; in every variety of country, from the Alps to the sandy plains of Germany; in every season,

in every change of weather, the continual movements of the barometer correspond in a most wonderful manner. The general law which governs these effects, within these limits, is constant in its operation, although subject to modifications which it will be highly instructive to trace and appreciate.

In the first place, the oscillations of the mercurial column decrease in proceeding from north to south; and in this way some of the minor movements are obliterated before they reach the extreme southern point. Hence, partly, it is that the three Mediterranean curves are not only flatter than the three Baltic, but less serrated and uneven. If the extreme northern and southern lines were placed in juxta-position, the resemblance would be but faint and imperfect; but they pass so gradually into one another, through the whole series, that their connexion is very manifest. These observations apply most accurately to those places which are situated nearest to the same meridian.

Secondly. There are other modifications which depend upon the relative distances of the places in longitude. By comparing together the most eastern and most western curves which nearly agree in latitude, it may be remarked that their several points would better correspond, if the former, that is, the eastern, were moved to the left hand about the space of a day or a half. This is more striking upon the larger scale, upon which they were originally laid down, but still may be satisfactorily established by an attentive examination of the plates. It is parti-

cularly obvious in the curves of Gottingen and Sagan, and in those of Marseilles and Rome. It is not dependent upon the difference of time, which is consequent upon the difference of longitude, for it is in the opposite direction; and, by taking the latter into consideration, the amount of the deviation is increased.

Thirdly. Besides this regular difference, there are occasional greater discrepancies as we change the longitude, traces of which are generally preserved throughout the meridian upon which they occur. For example, about the 4th of January, at Sagan, a very remarkable elevation of the line occurs, which differs very much from those at the same period at Gottingen and Erfurt, but which corresponds exactly with the curves of Prague and Buda. Again, about the 18th of March, a much bolder depression of the line occurs at Stockholm than at the same time at Spidberg and Copenhagen; and the same excess of effect may be traced down the more eastern meridians at Sagan, Prague, and Buda, by comparing them with their western neighbours. This difference, dependent upon longitude, will, however, be more distinctly marked, when we come to the explanation of the next plate.

Fourthly. The effect of the difference of the meridians becomes greater as we approach the Western Sea. It will at once be evident that the Brussels curve agrees the least with any of the others. Although it accords in the general outline, almost all the remarkable elevations and depressions are strongly

modified. The Marseilles curve, on the contrary, which is only one degree more to the east, agrees very closely with that of Rome. It will be remarked that the whole width of France interposes between this station and the Atlantic, while the former is at a comparatively small distance from the North Sea.

Fifthly. There is another modification which is dependent upon height. The mountain curve of St. Gothard is manifestly flatter, and its inequalities more rounded, than that of Geneva; and it is also worthy of remark how the relative distance of the two decreases as the temperature of the months increases, and augments with their decrease. In the summer the space between them is not half as great as it is in the winter. This is obviously caused by the expansion of the atmospheric columns in the former season; the difference of course manifesting itself in the increased weight of the upper section.

Sixthly. The abrupt and angular changes of the winter portion of the curves is strongly contrasted with the more gentle and rounded undulations of the summer months, and even the stormy portions of each with those of the more settled weather. These changes extend through the whole series; but it cannot but be remarked that the southern members of the group generally partake more of the latter, and the northern of the former, character.

Seventhly. It may be observed how very generally the corresponding angles of ascent and descent agree. There are certainly many exceptions to the rule, but it is almost universally true, that when the barometer

falls very abruptly, it rises to the same amount as suddenly, and *vice versâ.* This evidently points to the equality of action and reaction, and the cause of the exceptions themselves would form an interesting object of research.

Amongst the instructive relations of these comparisons, will be found the theory and practice of the mensuration of heights by the barometer. I shall not now attempt to trace out this connection in detail, but shall probably recur to it again upon some future occasion.

Before I turn from the consideration of the third and fourth plates, I must remark, that the observations, which were all registered in French inches, &c., have been laid down with the greatest fidelity, except in one or two instances, where the general accordance of the curves manifestly pointed out an error of *a whole inch.* Thus, for example, on the 5th of January, in the Spidberg curve, I have shown, by a dotted line, the course of such a mistake, which would have caused a wide departure from the character of the contemporaneous movements at other stations. I have corrected two other similar misprints; and there are a few other analogous discrepancies in different parts of the synoptic views, which may probably be referable to errors of the same description, but with which I have not ventured to interfere. Such, I am almost tempted to believe, is the sudden rise in the Stockholm line on the 31st January, and the anomalous fall in that of Spidberg on the 12th February. One of the uses to which, in future, this method of laying

down observations may be applied, is, to check, within certain limits, the accuracy of different observers.

The next most interesting objects of inquiry are the limits of this correspondence, and the commencement of the reflux which must necessarily accompany these extensive undulations; for the laws of equilibrium require that a fall of the mercurial column throughout the greater part of Europe, should be accompanied by a corresponding rise in other regions. Unfortunately the observations of the *Ephemerides*, extended as they were, are not sufficiently comprehensive to fix these important points with all the precision which we could desire. In Plate V., however, I have collected two groups which throw considerable light upon this part of the subject; and I shall now proceed to describe the stations from which they have been selected.

PYSCHMINSK, the nineteenth station, was the office of the mines in the Ural Mountains of Siberia, situated in the government of Perm. Its latitude is 57° N., and longitude 41° 4′ E. It is the most eastern point to which the registers of the Society extended. Its height was upwards of 2000 feet above the level of the sea.

PETERSBURG, the twentieth station, is situated on the river Neva, close to the Gulf of Finland. The ground in the neighbourhood is flat and low, and was formerly a vast morass. Its latitude is 59° 56′ N., and its longitude 30° 25′ E.

MOSCOW, the twenty-first station, is placed about 460 miles to the south-east of the last. The river

Moskwa runs through the city, and in the open country around are some small lakes, which give rise to the Neglina. Its longitude is 37° 31′ E., and its latitude 55° 45′ N.

MANNHEIM has been here introduced as the type of the western portion of the continent, in which we have already traced the movements of the atmosphere. From the comparisons afforded by this group we perceive,—

First, that there is neither agreement nor regular opposition in the course of the barometric curves, by extending the observations in the direction of the longitude. This is rendered quite obvious, by comparing together the lines of Pyschminsk, Moscow, and Mannheim, which are at nearly equal distances of 30° apart. I may further add that, in laying down the curve of contemporaneous observations at Cambridge, in the United States, contained in the Register, in longitude 70° 45′ W., and latitude 42° 25′ N., the same want of correspondence is observable.

Secondly, that the accordance is still maintained upon this remote meridian, in the direction of the latitude, as appears from the curves of Petersburg and Moscow, which agree together very exactly, notwithstanding they are not situated so nearly north and south as might be wished for the comparison. The quiet state of the atmosphere at Pyschminsk in the summer months of July and August, is another very interesting feature of its curve. This is probably the most inland station at which a register of the barometer has ever been kept, being almost exactly in the

centre of that immense extent of land which constitutes the continents of Europe and Asia.

GOTHAB, the twenty-second station, is situated upon the west coast of Greenland, in latitude 64° 10′ N., and in longitude 51° 18′ W. It is the most northern point of the *Mannheim Transactions.* It stands on the shores of Davis' Strait, at the foot of some very lofty mountains, which rise to the height of nearly 7000 feet. The barometer was placed about fifteen feet above the level of high-water.

EDSBERG, the twenty-third station, is a small town in Norway, not very far removed from the station at Spidberg, to which the observations, for some reason which is not explained, appear to have been transferred. Its latitude is about 59° N., and its longitude 9° E.

COPENHAGEN and MANNHEIM are again brought in, to connect the comparison with our previous remarks. I was unable to confine all the observations, as I should have preferred doing, to the same year, because there was no one year that included all the stations that were necessary to my purpose. This series of curves was not laid down like all the others, from two observations in each day, but from the mean of three; which gives them rather a rounder character, but does not materially alter their configuration. In this second group of the third plate, we can, I think, discover with sufficient distinctness, traces of that regular opposition of the curves, which could not but be anticipated from theory. Gothab is situated considerably to the north of all the other stations, and with the

interposition of the Atlantic Ocean. It is unfortunately more removed to the westward of the European meridians than could have been wished; but nevertheless the opposition of the movements of the barometer at the end of January, the whole of March, and parts of April and May, is almost perfect. The accordance of the three European curves of this group is sufficient to show that they are under the influence of the same law as in the former year, which we have more minutely traced. I have been unable in any way to follow up this interesting part of the subject, for the observations of Gothab have been only published for the six months which I have laid down.

Such being the state of the facts, we are now to inquire whether they are consistent with the general theory which I have proposed. In a system of balancing currents, as I have before observed, any cause which equally affects the velocity of two antagonist streams will change the weight of any perpendicular column, comprehending sections of the two; but, if either of them should be retarded or accelerated in its course without the other, or should they be unequally affected, their compound pressure must alter. We must conclude further, that such unequal change taking place at any particular point of the course of two antagonist currents, must manifest itself throughout their own line by opposite effects on each side of such point. Let us imagine two such currents: the lower flowing from the poles to the equator, and the upper from the equator to the poles, with such regular velocities that they exactly balance each other, and

their perpendicular pressure never alters. Suppose a sudden local check to be given at the centre point of the lower current: the upper will still move forward with its original velocity from its momentum; while the lower current still moving forward in advance of the supposed obstacle is fed by a reduced supply, and in the rear it will evidently go on accumulating up to the point of retardation. The barometer, therefore, which measures the combined pressure of the two currents must rise on one side and fall on the other. This rise and fall will also be sensible to the two extremities of the current, but in a decreasing ratio from the original point of disturbance, on account of the particles of the upper gradually losing their original impulse, and adapting themselves to a new arrangement and a new balance of velocities.

Now the order of the phenomena which we have been contemplating appears to me exactly to correspond with these theoretical conclusions. That part of the continent of Europe over which the observations extend lies about midway in the course of two antagonist currents of the atmosphere; which, from the distribution of the temperature of the globe, must, in an undisturbed state of a gaseous fluid, as I have elsewhere shown, flow between the pole and the equator. The whole line of its northern extremity, however, is bounded by the ocean, the evaporation from which must constantly disturb that regular progression of temperature upon which the balance of the two streams depends. The mode of this operation I have described at length in my first Essay: it will

be sufficient here to recall to remembrance, that it is by the heat evolved from the condensation of the rising vapour in the upper regions, and by the cold communicated by its re-evaporation, that such inequalities are produced. The actions and consequent re-actions produced by these irregularities we find constantly communicated from the north, where they originate, in a decreasing degree to the south. We also find that the counter-action of the barometer, which must necessarily exist somewhere, is not to be traced to the east or to the west; and although observations are wanting at the exact points where theory would teach us to seek it,—namely, to the north of the sea which bounds the northern coasts of Europe,—yet we find evidence of its existence upon the coast of Greenland; which, however, is too remote from the meridian of the chief observations, to present more than a slight correspondence.

The minor circumstances attending the principal phenomena accord no less with the theory. The modification to which the curves are obviously subject upon the shores of the Mediterranean are referable to the evaporation of that sea. The northern ocean is situated, with regard to the continent of Europe, in exactly the best position for producing powerful effects: by its means the warm waters of the Atlantic are brought in contact with the cold winds and ice of the Arctic Regions. In such a combination of circumstances, evaporation and condensation must reach the most violent extremes, particularly in the autumn and spring of the year. The vast undulations of the

aërial ocean dependent upon these circumstances are sometimes broken, but not destroyed, by the gentler influence of the southern waters*.

It is evident that the closest accordance of the curves is to be found amongst those which are situated the nearest to the same meridians; and the curves of the different meridians differ more widely from one another as they approach the Western Ocean. This is well exhibited by the Brussels line, which varies very considerably from those of Erfurt and Prague: while the curve of Marseilles, which is situated nearly as much to the west, but far removed from the western waters, agrees much more closely with those of Rome and Padua. The influence of the approach of water is also exhibited by the curves of Spidberg and Stockholm, which in their differences from that of Copen-

* While speaking of the circumstances which are best calculated to produce the greatest disturbance in the aërial currents, and which theory suggests to be the nearest approach of hot water to ice and cold, I may be permitted to observe, that I anticipated that the greatest oscillations of the barometer in this hemisphere would be found about the point where the Florida stream makes its nearest approach to the north. This conjecture I had an opportunity of verifying by the kindness of Lieutenant Bullock, of His Majesty's ship the *Snap*, who, while employed by Government in making a survey of the coast of Newfoundland, kept a very accurate register of the barometer. These observations I have laid down upon the scale; and, although they only extend over the summer months, and consequently those least calculated to exhibit the effect, their curve is decidedly more bold than that of any other situation I have traced at the same season of the year in any other part of the world.

hagen, are doubtless modified by the intervention of the Baltic Sea.

The precession of the western curves before the eastern may also be explained by the situation of the immense reservoir of vapour which is continually rising from the Atlantic Ocean: this, when wafted by the currents to the northern shores of Europe, can only progressively exert its influence along the successive meridians. We cannot but lament in this comparison the want of a corresponding station upon the north coast of Africa, from which, amongst many other interesting questions, the influence of the Mediterranean Sea would, probably, have been more clearly determined. In indulging, however, a wish upon this subject, it is difficult to restrain it within these limits, and not to extend it to the revival of a society similar to that of the Palatinate, and the extension of its operations in all directions.

It may possibly be objected to the theory, that these undulations extending over such a vast tract of the globe, cannot be supposed to depend upon any regular current of the air; because the wind is blowing at the same time in all directions with every modification of force. But it must be remembered that the winds, which are sensible to us, are influenced by local circumstances upon the surface of the earth, and are, compared with the grand movement of the atmospheric ocean, mostly parts of minor systems of compensation. It would be as reasonable to expect that the current which flows out of the upper part of a heated room, and is balanced by a counter-

current at the lower part, should affect the barometer, as that the direction which the wind assumes in a particular valley, or the retardation which it may experience against any particular mountain, should influence the general movement of the mercurial column. The currents to which the theory refers overtop the Alps, and sweep along uninfluenced by anything but changes in the elasticity of the medium, of which they form a part;—and thus it is that we find the same curve described upon the summit of St. Gothard and at the level of the sea. I do not mean to deny that these accidents of situation have a local and circumscribed influence; for even the sudden shutting of the door of a heated room, by which we affect the balance of its little system of currents, will cause a delicate barometer to oscillate; but they are lost in the grand outline which we have been considering.

Having traced the general accordance of the barometric curves in the situations which I have pointed out, it would doubtless be a very interesting and instructive task to enter into a further comparison of them, with a view of tracing the causes of their minuter differences; to inquire how far these may be referable to peculiarities of local situation, and to what extent they are connected with changes of weather. To do this to advantage, however, it would be necessary that the comparison should extend through a number of years. The materials are not wanting in the *Mannheim Transactions;* and indeed I have already laid down a far more extended number of

observations for the purpose; but the expense of engraving them is very considerable, and the attention at present given to the study of Meteorology is not sufficient to induce a publisher to undertake their execution with the hope of any advantage. The discovery, however, that the oscillations of the barometer are governed by some general law, which extends with unerring constancy over large tracts of the earth's surface, seems to me to give a new interest to the pursuits of Meteorology. It removes, in a great measure, the charge of uncertainty from its conclusions, and it opens a view of practical utility which is more likely to excite inquiry than the speculations of abstract science. That we may, hereafter, from observations properly arranged, be able to judge, at any moment of time, of the force of the winds at distant points will not, I think, appear chimerical to those who will attentively consider the phenomena which have just been developed; and it is not difficult to perceive that the interests of navigation may be deeply concerned in a knowledge of the laws of such fluxes and refluxes of the aërial ocean as those which we have been contemplating.

DESCRIPTION OF THE MAPS.

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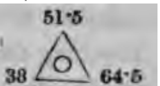
THE projection of the sphere adopted in these Maps, at once displays the striking difference between the proportions of land and water in the arctic and antarctic hemispheres; and farther it presents the advantage of allowing us to trace in unbroken curves the greater number of the isothermal lines that have hitherto been laid down.

The degrees of *latitude*, it will be seen, are marked in Roman figures upon the first meridian where the parallels cut it. The degrees of *longitude* are marked in a similar manner upon the equator, and also upon the great circle at the points where each meridian intersects it.

On the meridian of 30° W., the observed mean height of the *barometer* at the level of the sea in different latitudes, is placed from data furnished by Captain Sir J. C. Ross. From these it will be observed, as mentioned at page 182 of the present volume, that the mean pressure is greatest at and about the tropics, and that a sudden and remarkable diminution takes place as we approach the antarctic pole—a diminution much greater than in the corresponding latitudes of the northern hemisphere, due as it appears to the greater preponderance of water, and consequently of aqueous vapour, as we proceed towards the south pole. These heights of the barometer are projected in a curve upon the margin of the Map—the curve being intersected by the equator at its centre. The neutral line is here assumed to be thirty inches, and the elevation or depression of the column above or below this point, is laid down in inches on either side.

On the meridian of 20° W., the figures in italics indicate the degrees of *mean temperature* as calculated for the different latitudes, by Brewster's formula, (see p. 144). These are also repeated in italics on two points in the outer edge of the great circle where the parallels cut it. On the meridian of 90° E., as well as in various other places, Roman figures indicate the temperature of each isothermal line. Attached to most of the towns mentioned on this map, a small triangle will be seen; and at each of the angles, figures in italics. Thus Paris is

entered . . . . Paris 

These figures indicate the mean temperatures of the place to which they are affixed; the left hand figures (38) show the winter mean temperature, those to the right hand (64·5), mark the summer mean heat, while over the apex the figures (51·5) indicate the annual mean deduced from all the recorded observations.

A slight inspection of the isothermal lines will suffice to display two very remarkable facts; the first of these is the general depression of the curve, as we approach the north pole, when it passes over tracts of land of any extent, showing that in the colder climates the mean temperature of the continent is much lower than that of the sea in the same latitude. The effect of the land in the torrid zone is equally evident, but here it occurs in the opposite direction, the mean temperature of the continent being much higher than that of the ocean on the same parallel. It has been already pointed out that this tendency of the sea to maintain a general equilibrium of temperature over the earth's surface depends principally upon the mobility of its particles, and the convection or mechanical transport of the heat which it thus necessarily effects.

An instance of the cooling influence of land in high latitudes, is afforded by the curve of 32°, which, for the sake of

distinction, is marked by a double line. Commencing with the meridian in longitude 180°, it cuts the parallel of 60°. As it gains the mainland of America it touches the arctic circle. It then steadily and gradually descends as it sweeps across the continent until it reaches latitude 55°. On approaching Hudson's Bay, it again rises towards the pole, but is depressed to latitude 53° on passing across Labrador; it hence ascends by a gradual sweep past the coast of Greenland till it reaches Iceland, where another slight depression occurs; it then ascends to latitude 72°, in the sea of Greenland, and on reaching the North Cape, dips suddenly downward below the polar circle, rises slightly as it crosses the White Sea, and from that point sweeps downward across Siberia, till at 54° it passes over the central part of Asia, and thence slowly ascends till it again cuts the latitude of 60°, at the place from which we began to trace it. It is hence observable that even comparatively small surfaces of land and water exert a sensible influence in depressing or elevating the isothermal line.

But it will, in the second place, be obvious, on inspecting the Map, that though the mean annual temperature of all places on the same line is at equal altitudes the same, that the climate is by no means uniform throughout, for the mean winter and mean summer temperatures may vary within extensive limits, and, for reasons already adverted to, it is found in general that insular climates vary less than the continents on the same isothermal line. On the line of 50°, for example, the mean range of the climate of London is but 23°·5, whilst that of Washington is half as much again, being 35°, or 11°·5 greater.

It will also be remarked, that although the difference between the heat of the day and of the night is greatest near the equator, yet the nearer we approach the pole, the greater is the annual mean thermometric range, and *vice versâ;* an effect due in great measure to the very great and increasing variation in the obliquity of incidence of the sun's rays at

different seasons, as we approach the pole. At U Jansk, for instance, in latitude 71°, a difference of 86°, from −37°, the mean winter temperature, to +49°, the mean summer heat, is observable, while at Quito on the Andes, under the equator, the mean is 60° all the year round.

Upon the meridians of 90° E. and W., and the parallel of 80° N., are marked the situations of Brewster's hypothetical poles of cold, and their calculated mean temperature; the eastern pole has a temperature of +1°, the western pole of −3°·5, (p. 144.) These are not centres whence cold emanates, but mere resultants, the depression of the more northerly curves over Asia and America, arising, as it would appear, from the general cooling influence which land exercises.

The dotted undulating line near the equator, represents the line of mean highest heat.

For the convenience of reference a table of places of which the temperatures are recorded on the Maps, is appended to this description.

Currents, both of the atmosphere and of the ocean, and their prevailing direction, are indicated by arrows. The large single-headed arrows between the tropics show the course of the *trade winds*, commencing in a direction nearly due east, and gradually drawing round through N.E. and N.N.E., and S.E. and S.S.E., as they approach the equator, till they blow directly north and south. For 2° or 3° on each side of the equator, double-headed arrows crossing each other indicate the situation of the *variables* between the north and south trade winds. For two or three degrees above the latitudes of 30° double-headed arrows, running east and west, show the variable winds occasioned by the gradual intermixture of the polar and equatorial currents, and still further north and south the ultimate prevalence of the current from the equator is shown by the westerly direction of the arrows in this part. In the North Atlantic this conflict between the two currents is more undecided;

the general direction of the winds, north-east and south-west, is marked by the arrows pointing in these directions, and the greater prevalence of the south-westerly wind is shown by the double barb. A similar mode of representation indicates the predominance of the north-westerly gales as we approach the pole.

Local circumstances modify this general direction of the winds: thus, in the Mediterranean they usually blow north and south, the greater frequency of the northerly wind being shown as before by the double barb.

Small double-headed arrows will be seen ranged vertically around the coasts between the parallels of 40° N. and 40° S. These show the existence and direction of the *land and sea breezes* that daily occur in these latitudes. It will be observed, that in seas of comparatively small extent, like the Red Sea and the Mediterranean, no such regular alternation of land and sea breeze prevails, the differences in the temperature not being sufficiently great.

The *Monsoons* are represented by large double-headed arrows. These, in the northern hemisphere, from November to March, blow from the north-east; during the remaining six months (from April to October), they blow from the south-west. Amongst the Indian Islands, to the south, the monsoons are shown blowing from the north-west and south-east, for reasons explained pp. 183 and 184: the north-west prevailing from November to March, and the south-east from April to October.

The usual direction of the *rotatory storms* of the tropics is pointed out by a circular arrangement of arrows: north of the equator, as in the Gulf of Mexico, the wind on the east side of the vortex blows from the south, and from the north on the western side. In the vortex marked south of the equator, near Madagascar, the arrows show that the wind takes a direction exactly the reverse; this would necessarily result from the opposite directions taken by the upper atmo-

spheric currents north and south of the equator. The breaking down of these into the lower currents appears, as stated at p. 200, to be the cause of these violent tornadoes.

The currents in the ocean are marked by continuous lines of shading; those parts where the stream is most powerful, being shaded darkest; the direction is shown by arrows, which are stronger and deeper than those indicating the aërial currents. We are thus enabled to trace the current northwards from the heated coast of South Guinea deflected westward by the projecting north coast of the same country; by the promontory of St. Roque, in South America, it is split into two streams, one of which turning southward mingles its waters with a similar current from the Cape of Good Hope, while the northern and larger portion sweeps the coasts of the Gulf of Mexico, receives a fresh addition of heat in these torrid climes, and escapes in a powerful current between Florida and the adjacent islands, and thus constitutes the Gulf Stream, which gradually expends itself upon the western shores of Europe. In consequence the opposite directions assumed by the two great limbs of this current the sea between the Equatorial and Gulf Streams is comparatively motionless. Floating matters here accumulate, and it is constantly covered with weeds. This tract is indicated on the chart as the Sea of Sargasso, or sea of weeds.

Accompanying the Map is a moveable diagram, on which the transverse lines show the heights of some of the principal mountains, which have been laid down on a scale of 10,000 feet to the inch. The relative position of the mountains, as regards their distance from the equator and poles, will be seen by applying the diagram to the meridian of Greenwich, in the Atlantic hemisphere, so that the degrees of latitude upon the diagram and the map shall correspond. The mountains west of London are placed on the left-hand side of the diagram; those of the east on the right-hand side. The curved margin of the shaded space represents the elevation at

which, according to calculation, (see p. 207,) the plane of *perpetual snow* should occur. The height, in feet, of this calculated line is expressed on the diagram for every ten degrees of latitude. Each of these intervals is marked by a faint line traced across the shaded portion. From various circumstances alluded to in the Essay to which reference has just been made, the actual snow line is often considerably elevated, especially by the radiation of heat from the surface of large continents. The portion of the mountain below the snow line is indicated by a darker line, whilst the fainter prolongation shows the height to which the snow-capped peak rises beyond this point. In a few cases where the actual snow line is not known, the elevation to which the mountain extends above the calculated snow plane is indicated by a dotted line. The principal of these mountains are included in the following Table. The mountains on the western side, being for the most part situated near the sea-coast, follow the calculated snow line much more exactly; there is no salient exception, like the Himalayan range in the eastern hemisphere. Simple inspection of the diagram will show that, speaking generally, the height of the mountains increases as we approach the equator, provision being thus made for the constant supply of water in tropical climates where it is so much needed, by the condensation and arrest of the moisture effected by these elevated chains, and the gradual melting away of the snow which accumulates upon them.

TABLE (LXII.) *of the Heights of some of the Principal Mountains, and of the observed Limits of Perpetual Snow.*

NAME.	Lat.	Long.	Height in Feet.	Snow Line.
EAST.				
	° ′	° ′		
Hammerfest	70 42 N.	23 3	2,345	2,345
Alten	69 47	23 35	3,517	3,517
Sulitelma	67 4	15 35	5,910	4,117
Dovrefeldt	62 20	10 10	4,875	4,790
Chevelutch	56 40	160 20	10,591	5,250
Altai	49 15	....	11,000	7,034
Mont Blanc	45 51	6 54	15,650	8,884
Elbrouz	43 21	42 48	17,796	11,063
Vesuvius	40 50	14 30	3,938	....
Ararat	39 37	44 22	17,266	14,113?
Argæus	38 33	43 28	13,100	10,702
Etna	37 30	15 5	10,874	9,531
Hindoo Kho	34 30	72 20	20,800	12,980
Chumularee	28 0	89 0	29,000	17,000
Mountains of Geesh	13 10	....	15,000	14,065
WEST.				
Mount Hecla	63 50 N.	20 10	4,887	....
Ben Nevis	56 48	5 0	4,350	4,350
Mont Perdu	42 37	0 0	11,283	8,400
Long Peak	40 30	106 30	13,430	....
Mulahacen	37 10	....	16,512	11,187
Mount Atlas	31 15	7 20	12,050	....
Mount Teneriffe	28 0	17 15	12,180	....
Mouna Kea	19 50	155 0	18,400	....
Popo Catapetl	19 0	....	17,716	14,977
Nevada Merida	8 5	71 20	16,420	14,928
Pichincha	0 12	78 55	15,940	15,700
Chimborazo	1 30	79 2	21,460	15,804
St. Helena	16 0 S.	6 0	2,700	....
Nevada de Sorata	16 10	68 50	25,250	15,922
Nevada de Illimani	17 12	68 22	24,450	15,922

TABLE (LXIII.) *of the Mean Winter, Mean Summer, and Annual Mean Temperature of Places mentioned on the Maps.*

NAME.	Lat.	Long.	Winter Mean Temp.	Summer Mean Temp.	Annual Mean Temp.
	° ′	° ′	°	°	°
Melville Isle	74 47 N.	110 42 W.	−28	+37	− 2
Igloolik Isle	69 19	80 57	−21·5	+35	+ 2
U. Jansk..................	70 55	138 30 E.	−37	+49	+ 2
Port Bowen................	73 14	88 49 W.	−25	+37	+ 3·5
Winter Island............	66 11	83 5	−20·5	+35	+ 6·5
Fort Enterprise	64 28	113 0	−23·5	....	....
Jakutsk	62 1	129 13 E.	−38	+63	+14·5
Nova Zembla .... {	70 37	57 53	− 3	+35·5	+15
	73 0	53 56	− 2·5	+40	+17
Fort Franklin............	62 12	123 7 W.	−17	+50·5	+17
Fort Reliance	62 46	106 35	−20·5	....	....
Spitzbergen	80 0	16 26 E.	....	+38	....
Sea of Greenland ....{	78 0	9 26	....	+35	+18
	72 0	18 34 W.	....	+35	....
	80 0	10 26 E.	....	+35	....
Nain (Labrador)........	57 10	61 44 W.	− 1·5	+46	+25·5
Fort Simpson	62 11	121 26	−10	+59	+26
Gothab......................	64 10	51 8	....	....	+26·1
Enontekis	68 40	22 26 E.	+ 1	+55	+27
Irkutsk	52 16	104 24	0	+60·5	+28·5
Werchoturia	59 0	62 0	....	....	+30·5
North Cape	71 10	25 56	−24	+43·5	+32
Umeo	63 50	20 22	+14	+57·5	+37
Kazan	42 53	26 30	+ 6	+62·5	+36
Petersburg	59 56	30 25	+17	+60	+38
St. John's	47 34	52 32 W.	+23	+54	+38
Moscow	55 45	37 44 E.	+13·5	+62	+39
Oonalashka	53 52	166 19 W.	+33	+51·7	+40
Fahlun	60 39	15 51 E.	+22	+58	+40
Abo	60 27	20 23	+22	+60	+40·5
Port Famine	53 38 S.	70 48 W.	34	....	....
Quebec	46 42 N.	71 16	....	....	41·9
Christiania	59 54	10 51 E.	25	59·5	42
Stockholm	59 21	18 9	26	61	42
Halifax	44 39	63 31 W.	24	63	43
Montreal	45 31	73 29	17·5	69	44
Tilsit	55 4	21 59 E.	25·5	62	44
Toronto	43 39	79 21 W.	26·5	63 8	44·4
New Archangel	57 3	135 12	33	55	44·5
Warsaw	52 13	21 8 E.	27·5	63·5	45·5
Dantzic	54 21	18 44	30	61·5	46
Stromness	58 57	3 23 W.	39	54	47
Breslaw	51 6	17 8 E.	30	63	47
Falkland Isles	52 0 S.	60 0 W.	....	....	47
Jena..........................	50 56 N.	11 43 E.	31	62	47·5
Edinburgh	55 57	3 6 W.	38·5	58	47·5

TABLE LXIII. *continued.*

Name.	Lat.	Long.	Winter Mean Temp.	Summer Mean Temp.	Annual Mean Temp.
	° ′	° ′	°	°	°
Berlin	52 31 N.	13 29 E.	30	63	47·5
Astracan	46 18	48 5	....	....	49
Dublin	53 23	6 15 W.	40	66·5	49
Munster	51 58	7 44 E.	37	62	49
Vienna	48 13	16 29	32·5	68·5	50
Brussels	50 51	4 28	38	65	50·5
London	51 31	0	39·5	63	51
Paris	48 50	2 26	38	64·5	51·5
Auckland	34 0 S.	174 0	51	67	52
Penzance	50 7 N.	5 27 W.	44	62	52
Hobart Town	42 45 S.	147 41 E.	42	63·5	52
Sevastopol	44 36 N.	33 38	35·5	71	53
Boston	42 21	70 58 W.	36	69	53
Turin	45 4	7 48 E.	33·5	72	53
New York	40 46	73 58 W.	....	....	53·8
Padua	45 24	11 58 E.	37	71·5	54·5
Pekin	39 54	116 35	26	83	55
Washington	38 53	76 56 W.	36	71	55
Constantinople	41 0	28 55 E.	40·5	73·5	57
Bordeaux	44 50	0 29 W.	43	71	57
Rhodes	36 26	28 13 E.	....	....	57
Madrid	40 25	3 36 W.	42	74	58
Port Nicholson	41 22 S.	174 45 E.	50·7	65·2	58·2
Toulon	43 7 N.	6 2	47·5	72	59
Rome	41 54	12 34	46·5	73	60
Quito	0 14 S.	78 39 W.	60	60	60
Naples	40 51 N.	14 21 E.	50	75·5	62
Lisbon	38 42	9 3 W.	52	71	62
Mexico	19 26	99 0	55·5	66·5	62
Buenos Ayres	34 37 S.	58 18	52·5	73	62·5
Barcelona	41 22 N.	2 17 E.	50	76	63
Laguna (Teneriffe)	28 30	16 13 W.	56·5	68·5	63
Abbeville (Carolina)	34 10	82 20	47	80	63·5
Algiers	36 47	1 43 E.	54	74·5	64
Coquimbo	29 30 S.	70 40 W.	....	....	64
Conception	36 42	70 50	....	....	64
St. Michael's	39 0 N.	27 0	60	69·3	64·3
Gibraltar	36 7	5 15	57	73	64·5
Paramatta	33 50 S.	151 16 E.	54·5	74	64·5
Savannah	32 5 N.	81 1 W.	51·5	77	64·5
Nangasaki	32 57	130 0 E.	47·1	81·8	64·9
Near Natchez	31 34	91 19 W.	50	78	65
Funchal	32 38	16 49	61·5	70	66
Messina	38 11	15 40 E.	55	77	66
Cape Good Hope	33 55 S.	18 34	58·5	74	66·5
Monte Video	34 54	56 7 W.	57·5	77·5	67
New Orleans	29 58 N.	90 11	53	80	67

TABLE LXIII. *continued.*

Name.	Lat.	Long.	Winter Mean Temp.	Summer Mean Temp.	Annual Mean Temp.
	° ′	° ′	°	°	°
Bermuda	32 20 N.	69 30 W.	59	75·5	67·5
Tunis	36 48	10 17 E.	56	83	68·5
Arequipa	6 0 S.	75 0 W.	....	....	69
Canton	33 8 N.	113 22 E.	55	82	70
St. Croix (Teneriffe)	28 28	16 10 W.	64·5	77	71·5
Caraccas	10 31	66 55	69·6	74·1	71·6
Cairo	30 2	31 21 E.	58·5	84·5	72·5
Candy	7 18	80 56	72	72	73
Rio Janeiro	22 55 S.	43 10 W.	68·5	79	73·5
Bagdad	33 20 N.	44 25 E.	....	....	74
Pt. Ahuja	5 0 S.	82 0 W.	....	....	74
Oahu	22 0 N.	158 0	59	88	75
Owhyhee	20 0	155 0	71	78	75
St. Louis	16 1	16 27	70	82	76·5
Tahiti	17 0 S.	148 0	76·3	78·2	76·8
Pounah	18 30 N.	69 34 E.	71	79	77
Havannah	23 9	81 17 W.	73	81·5	77
Vera Cruz	19 12	96 3	71	82	77
Seringapatam	12 45	76 47 E.	73	76	77
Benares	25 19	83 1	61·5	85·5	78
Ava	21 40	116 6	69	84	78
Manilla	14 35	121 2 E.	....	....	78
Calcutta	22 35	88 26	67·5	83·5	78·5
Bombay	18 56	73 0	74	83	79
Jamaica	17 50	76 36 W.	76	81·5	79
Tortola	18 27	64 34	78	80·5	79
Singapore	1 17	103 56 E.	78·5	81	80
St. Bartholomew	17 53	62 54 W.	79	81·5	80
Mauritius	20 10 S.	57 30 E.	....	....	80·4
Batavia	6 9	106 59	79	81	80·5
Cumana	10 28 N.	64 4 W.	80·5	82·1	81·5
Trincomalee	8 34	81 28 E.	78	84	81·5
Coast of Guinea	5 30	0 34 W.	79·5	82·5	81·5
Madras	13 5	80 23 E.	76·5	86	82
Leon	12 16	86 37 W.	....	....	82
Para	1 27 S.	48 15	84	84	84
Maracaybo	11 19 N.	74 3	82	87	84·5
Massowa	15 36	39 35 E.	80	89·8	88

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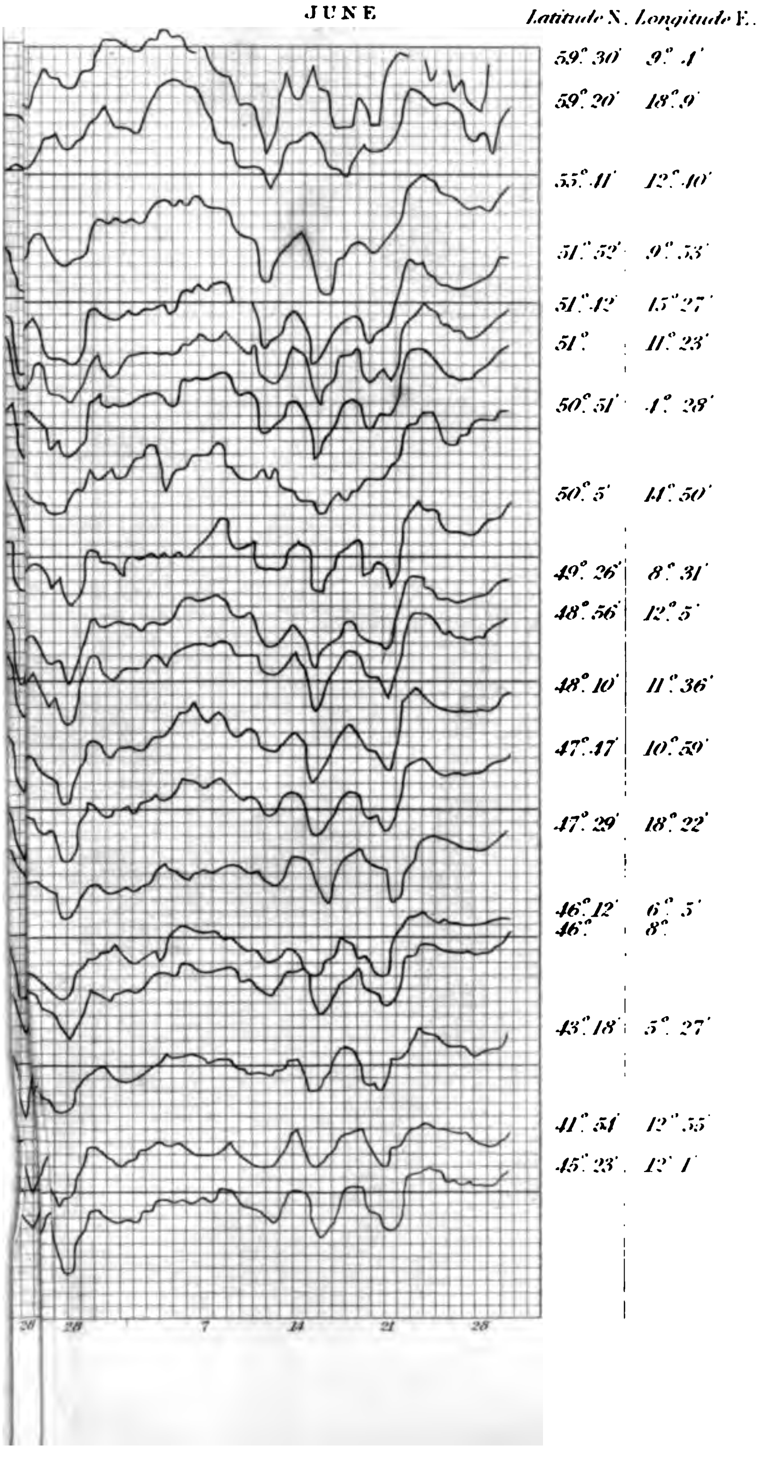

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